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AUGMENTED TARGET SCREENER / FLIR SYSTEM

Honeywell Inc.
Systems and Research Center
2600 Ridgway Parkway
Minneapolis, Minnesota 55413

JULY 1976

TECHNICAL REPORT AFAL-TR-76-152

FINAL REPORT for PERIOD MAY 1975 - MAY 1976

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

This technical report has been reviewed and is approved for publication

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This report describes the concept, functions, implementation, and performance of the Augmented Target Screening Subsystem (ATSS) configured to screen FLIR imagery. The ATSS may be either an airborne or ground-based device that operates directly on the output video signal of a FLIR sensor or on FLIR data recorded on a video tape. The ATSS has analog and special purpose digital equipment, and a general purpose computer which are combined with peripheral equipment (displays, Visicorder, interfaces, scan converter, and cameras) to perform automatically and in real-time target

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screening. Using imagery signal processing, the ATSS detects and extracts target features and uses pattern recognition techniques to classify man-made objects. The ATSS performance was evaluated at several stages with the final results indicating that the design goal (probability of detection 0.85 and false alarm probability 0.07) was met.

FOREWORD

This is the final report on Air Force Contract F33615-75-C-1234, prepared by Dr. Meletios Geokezas for the Air Force Avionics Laboratory, Project 665A, Task No. 04-26. It describes the theory of operation, the hardware and software modifications, and the performance evaluation of the Autoscreener/FLIR system and concludes with conclusions and recommendations.

The program was managed by Dr. M. Geokezas under the supervision of Dr. G. B. Skelton initially and then under Dr. N. R. Zagalsky.

Mr. R. J. Matthys was responsible for the hardware modification and contributed to the final report, while Mr. K. Fant was responsible for the digital hardware and software modifications and the performance evaluation of the Autoscreener/FLIR system and contributed to the final report. Mr. L. Towers did the necessary drafting.

Requirements and functional characteristics of the Autoscreener/FLIR system were specified in RFP No. F33615-75-R-1234 of March 18, 1975. The effort on this contract was initiated on May 20, 1975 and completed on May 28, 1976.

Honeywell Inc., Minneapolis, Minnesota, selected the scan converter (PEP-400R), the monitor (Conrac DZA), and the Video Tape Recorder (Sony AV-3600). This equipment was purchased by the Air Force and supplied as GFE. Honeywell designed and fabricated three interfaces and modified the hardware and software of the original Autoscreener in order to make

it compatible with the TV-compatible FLIR system. The system is operational, and its performance was evaluated with FLIR imagery. The results indicate that 95 percent probability of target detection was achieved with five percent probability of false alarm.

Honeywell acknowledges the management direction and guidance of the project manager, Mr. R. Jennewine, AFAL/RWI, and project engineer, Capt. K. Winges, ASD/ENAMC, Wright Patterson Air Force Base.

This report was submitted by the author on June 17, 1976.

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SECTION 1

INTRODUCTION

This report describes the work supported by the Air Force Avionics Laboratory, 665A Program Office, under Contract F33615-75-C-1234, and performed by Honeywell Inc., Minneapolis, Minnesota, from May 20, 1975 to May 28, 1976.

The Augmented Target Screener Subsystem* (ATSS, Autoscreener) was designed and built by Honeywell and delivered to the Air Force in 1974. This system operated on imagery data from an AAS-27 sensor, detected man-made objects (MMOs), and cued the operator by displaying a symbol at each sector area (1/16 of a frame) containing one or more MMOs. It operated at a rate of 200 scan lines per second and achieved about 90 percent probability of detection of MMOs and less than 3 percent probability of false alarm.

The good performance of the Autoscreener with the AAS-27 sensor suggested a follow-on program to evaluate the feasibility of a target cueing system with a FLIR sensor.

The primary objective of this program was to evaluate the feasibility of an Autoscreener/FLIR system in detecting man-made objects and cueing the FLIR operator. However, the FLIR sensor is TV-compatible (30 frames per second, 525 scan lines per frame) and was incompatible with the

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* "Augmented Target Screener Subsystem" (ATSS) Final Technical Report, AFAL-TR-74-184, October 1974.

Autoscreener. Therefore, the secondary objective of this program was to modify the Autoscreener so that it would be compatible with a FLIR sensor.

Both objectives were accomplished. The secondary objective was met by hardware and software modifications of the existing Autoscreener system. This was the most cost-effective and fastest approach. The primary objective was met by evaluating the performance of the Autoscreener/FLIR system in detecting and cueing man-made objects. The results--95 percent probability of detection and 5 percent probability of false alarm--achieved with a limited data base are comparable to the results with the AAS-27 sensor.

The contents of this report are summarized in Section 2, while the details are presented in the following sections; that is, Section 3 discusses the theory of operation of the Autoscreener/FLIR system, Section 4 discusses the hardware and software modifications, Section 5 discusses the Autoscreener/FLIR performance evaluation, and Section 6 presents the conclusions and recommendations.

SECTION 2

SUMMARY

The summary of Sections 3, 4, 5, and 6 follows.

SUMMARY OF SECTION 3: THEORY OF OPERATION OF THE AUTO-SCREENER/FLIR SYSTEM

A functional block diagram of the Autoscreener/FLIR system is presented in Figure 1. The Sony AV-3600 video tape recorder plays back the FLIR tapes. The video imagery is displayed continually on the Conrac DZA monitor. About every one second, two successive frames are averaged and stored in the electrostatic storage tube of the PEP-400R scan converter on command from the Autoscreener. The stored imagery, on command from the Autoscreener, is read out through Interface #2 at a rate of about one scan line per millisecond. The imagery of every scan line is then processed by the Autoscreener to extract the first level features (steps and brightness) which are combined to extract the candidate object intervals. Congruent candidate object intervals over successive scan lines map out candidate objects from which seven features are extracted and used either off-line to train a linear K-class classifier and then store the classifier coefficients in the computer memory or on-line to classify each extracted object into man-made objects (MMOs) and nuisances and generate a symbol if one or more MMOs are present in a sector (1/16 of a frame).

The first level features and candidate object intervals may be displayed on the first level display.

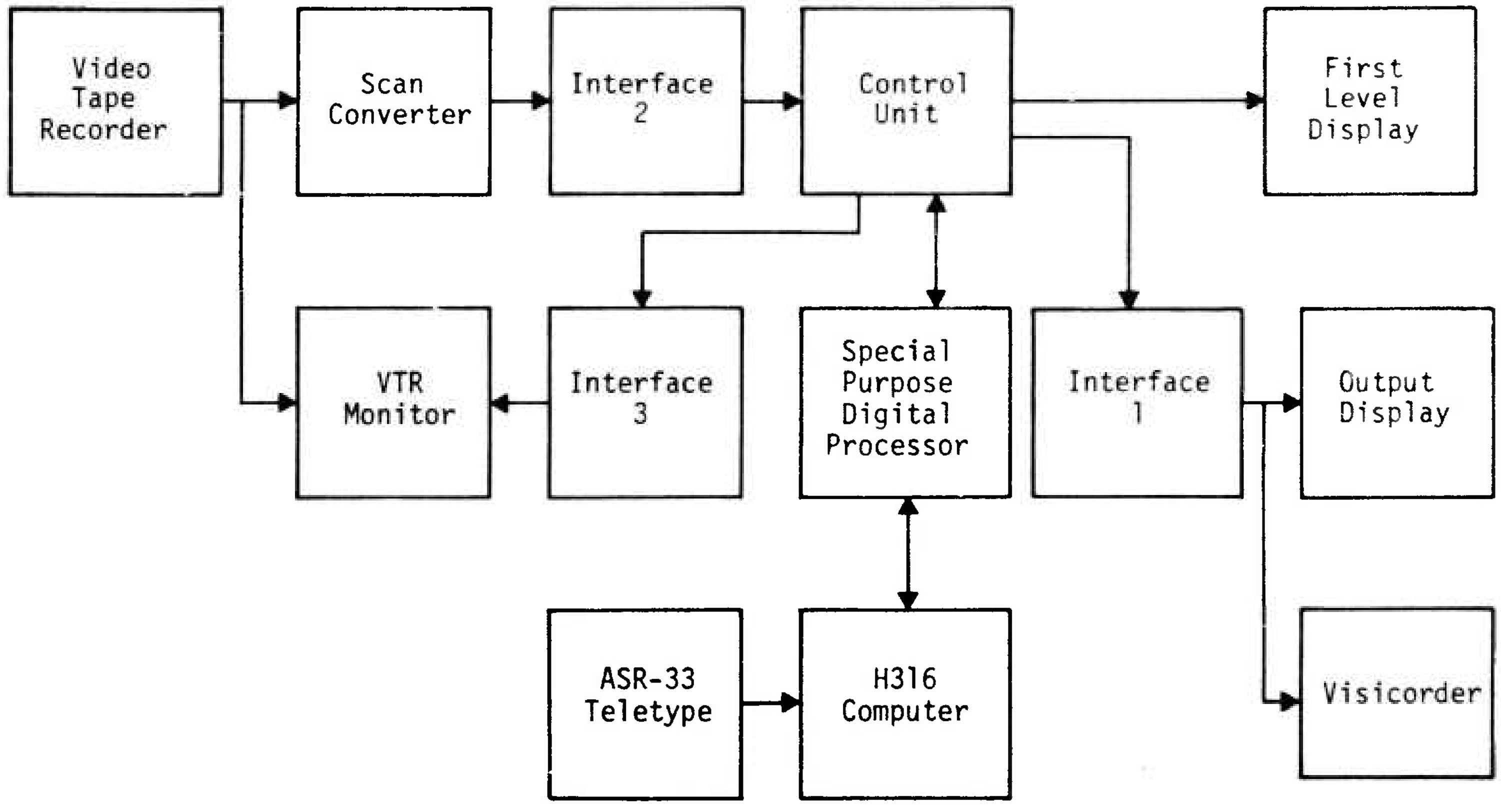

Figure 1. Functional Block Diagram

The imagery read out from the scan converter is displayed on the output display as well as on the Visicorder for hard copy. In addition, through Interface #1, the symbols indicating the presence of MMOs are displayed on the output display and Visicorder.

The symbol is also displayed on the VTR monitor through Interface #3.

The operating instructions are referenced and, in the theory of operation, the scan converter, the raster format, the control unit's first level features, and the digital processor's interval detect are discussed.

SUMMARY OF SECTION 4: HARDWARE AND SOFTWARE MODIFICATIONS

The following modifications of the original Autoscreener were made:

Deletions:
- 201 computer
- Core memory for 201 computer
- Krohn-Hite 5100A voltage control oscillator

Additions:
- PEP-400R scan converter
- Sony AV-3600 Video tape recorder
- Conrac DZA monitor
- Input symbol mixing circuitry
- Audio alarm, activated by MMO symbols

Changes:
- Parallel reading of the step and brite counters
- New raster and symbol generator for the output display and Visicorder
- Digital processor

The hardware modifications relating to the scan converter, read (output) raster generator, output and input symbol generator, audio alarm generator, and digital processor, as well as the on-line and off-line software modifications, are discussed in this section.

SUMMARY OF SECTION 5: AUTOSCREENER/FLIR PERFORMANCE EVALUATION

Prior to the performance evaluation of the Autoscreener/FLIR system, sixteen frames were used for the training of the classifier. The original seven Autoscreener features were extracted, and their histograms were determined. The classifier was trained off-line, and the classifier coefficients were stored in the computer and used for testing the classifier.

The performance of the Autoscreener/FLIR system was evaluated with about 350 frames from eleven imagery segments selected from four video tapes containing tactical targets, rural and urban imagery.

Two sets of thresholds were used for the high contrast hot and cold and step first level features. The processed frames with the symbols superimposed were recorded on the Visicorder and compared with the raw video to score the sectors. The number of frames, the number of sectors with MMOs, the number of detected sectors with MMOs, and the number of false alarms were determined and tabulated from which the probabilities of detection and false alarm were evaluated, plotted, and compared with results of the Autoscreener with the AAS-27 sensor. The results are presented in Figure 2. The two points on the Receiver Operating Characteristics curve correspond to P_D = 94.6 percent with P_{FA} = 4.5 percent and P_D = 84.5

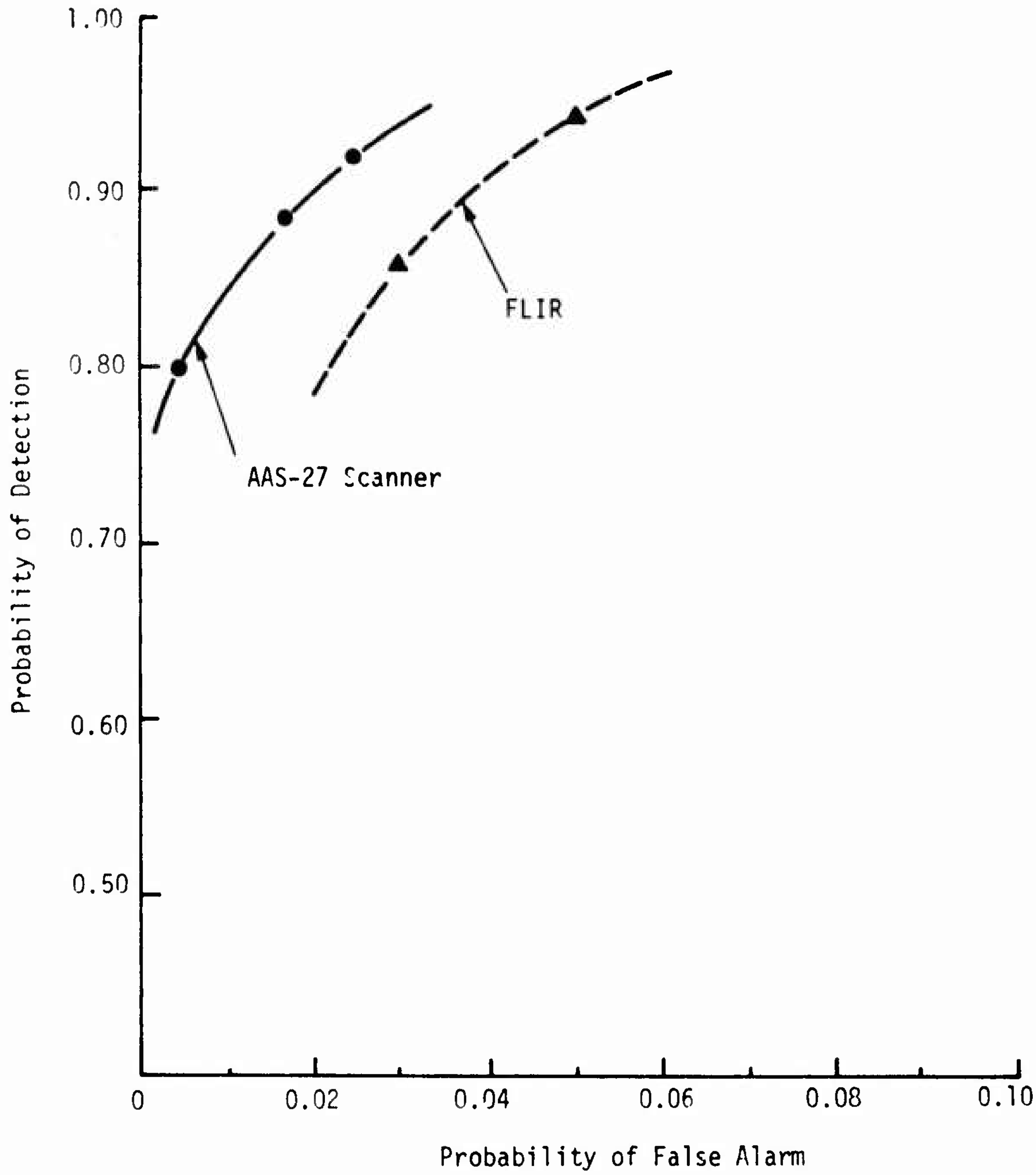

Figure 2. Autoscreener Performance: Sector Basis

percent with $P_{FA} = 2.8$ percent. The results are certainly very satisfying and encouraging.

SUMMARY OF SECTION 6: CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are made:

1. We have established the feasibility in detecting man-made objects and cueing the FLIR operator with the Autoscreener. We achieved 95 percent probability of detecting MMOs with less than 5 percent false alarm probability.

2. The scan converter is an interim, very cost-effective, and fast approach in assessing the feasibility of the Autoscreener/FLIR system for detecting MMOs and cueing the FLIR operator.

3. The FLIR imagery (aspect angle dependence) is not so well behaved as the AAS-27 imagery. The intensity increases from the top to the bottom of a frame and varies inversely proportionally to the range squared from the sensor to the object. Thus, the absence of an AGC circuit and automatic threshold has a detrimental effect on the results.

4. The seven feature histograms indicate that we may have correlated features.

5. The MMO symbol is generated approximately every second and shows correctly the pres ice of MMOs on the output display and Visicorder. On the monitor, the TV-compatible FLIR imagery is continually displayed and, because of the relative motion between the target and object, the symbol is displayed

with up to two seconds delay with respect to the processed imagery. This makes it appear that there are missed targets and false alarms. This can be corrected with a faster processor.

The following recommendations are made:

1. The Autoscreener/FLIR system with an autothreshold will take care of the aspect angle and range dependence of the FLIR intensity and will automate the operation of the system.

2. Now that the feasibility of detection of MMOs is proved, we must turn our attention to the detection and recognition of tactical targets. We must study the optimum selection of geometric and texture features, the classifier design, and evaluate the performance of the Autoscreener on a wide data base.

3. The first generation Autoscreener is a reality. Now is the time to consider the second generation Autoscreener. This should include an in-depth study to define requirements for the appropriate mission scenarios. We must study in greater detail the speed of operation, the processing algorithms, the features for tactical target detection and recognition, the hardware implementation for a small, light-weight, cost-effective and fast Autoscreener. Finally, the Autoscreener application for ground-based and airborne systems should be investigated and tested.

SECTION 3

THEORY OF OPERATION AND SYSTEM DESCRIPTION

The theory of operation of the Augmented Target Screening Subsystem (ATSS, Autoscreener) is discussed in detail in Volume 1 - System Operation and Maintenance, Augment Target Screener Subsystem.

The Autoscreener was modified to operate with a FLIR sensor. The theory of operation of the Autoscreener/FLIR system is discussed in this section.

SYSTEM DESCRIPTION

The Autoscreener/FLIR system functional block diagram is presented in Figure 3. The function of the control unit, special purpose digital processor, H316 computer, first level display, output display, Visicorder, and ASR-33 teletype remains the same and will not be repeated. The function of the remaining units is discussed next.

The function of the video tape recorder (Sony AV-3600) is to play back the TV-compatible FLIR tapes. The output of the video tape recorder (video and sync signals) is continually displayed on the TV monitor, and approximately every one second, two successive frames are averaged and stored in the scan converter (PEP-400R).

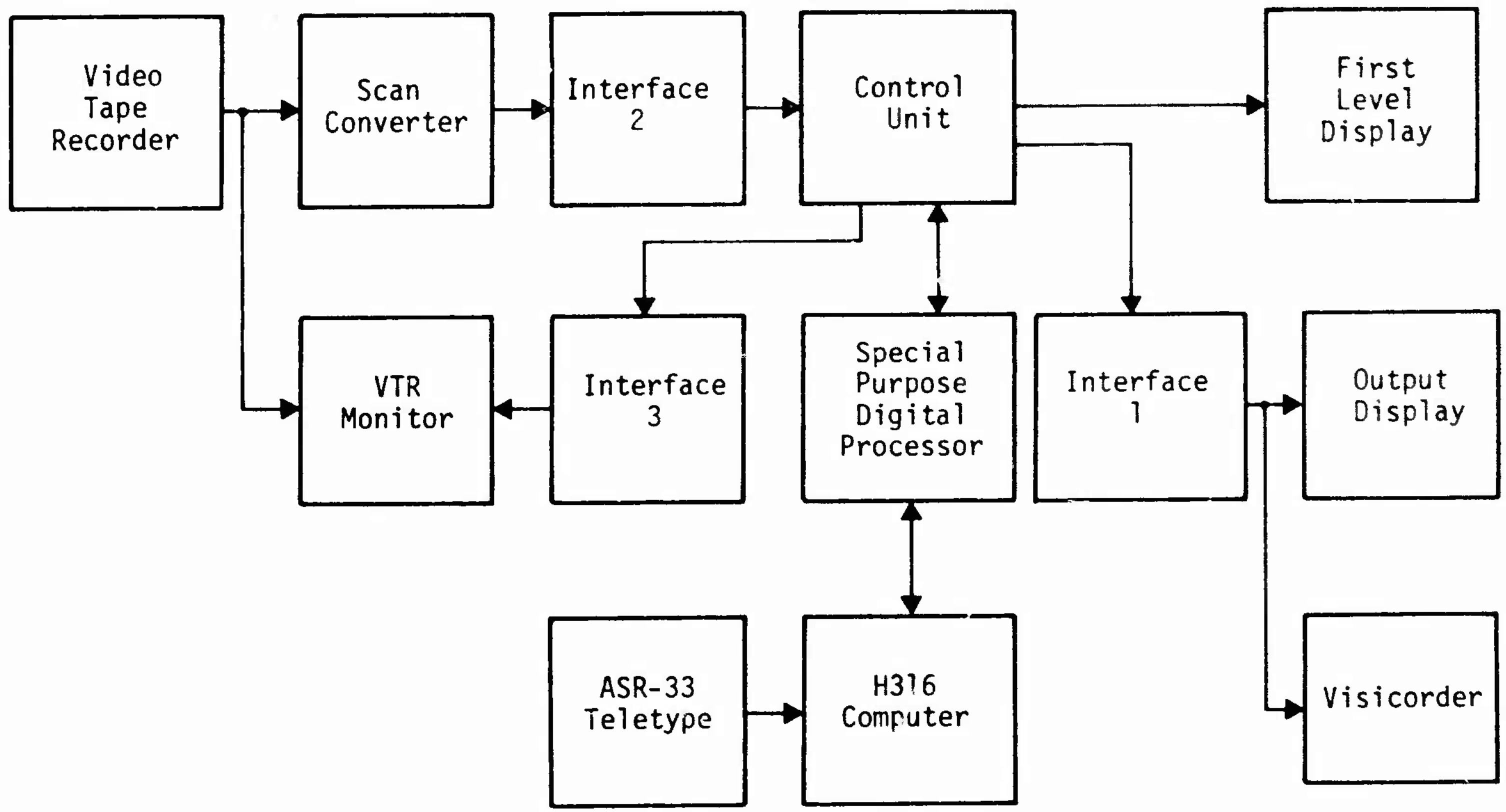

Figure 3. Autoscreener/FLIR System Functional Block Diagram

The function of the scan converter is to store one frame at the TV rate (30 frames per second) and read it out on command from the control unit at a slow rate of one frame per second which is the rate the present Autoscreener hardware operates.

Interface #2, between the scan converter and the Autoscreener, supplies the necessary paths for the video, input and output raster, and blanking signals.

Interface #3 contains the electronics for generating the symbol for the VTR monitor. The monitor display is sectored into 16 equal sectors as shown in Figure 4. The symbol consists of three black-white vertical bars, and it is displayed approximately at the center and below a sector if that sector contains one or more man-made objects. Its hardware implementation is discussed in Section 3.

Interface #1 in a similar fashion contains the electronics for generating the symbol for the output display and Visicorder. The symbols are as shown in Figure 4.

OPERATING INSTRUCTIONS

The procedure for operating the Autoscreener/FLIR system is described in Volume 1 of the System Operation and Maintenance Manual, and it will not be repeated here.

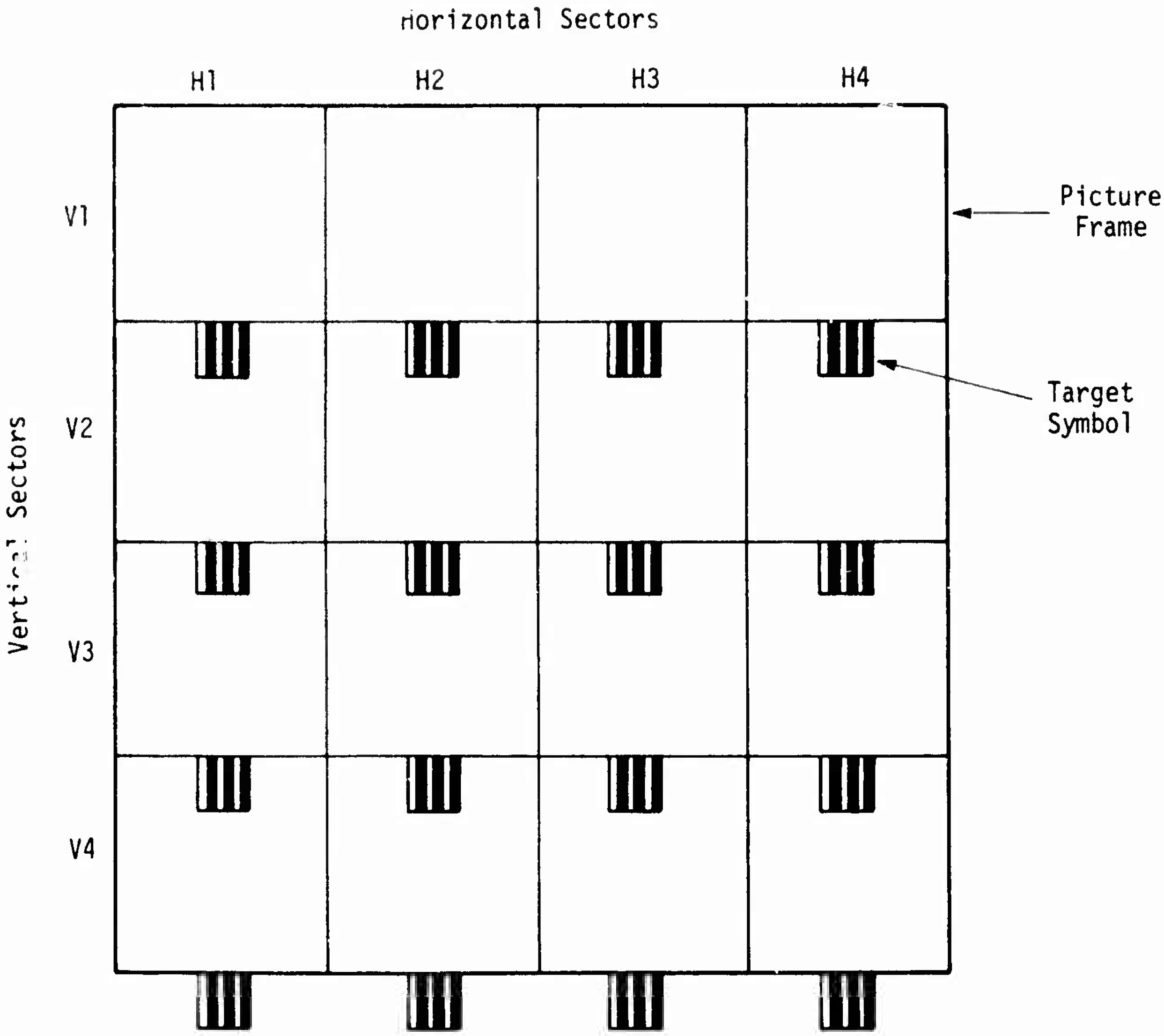

Figure 4. Target Symbol Grid

THEORY OF OPERATION

The theory of operation of the Autoscreener is discussed in detail in Volume 1 - System Operation and Maintenance. In this section, the theory of operation as related to the modifications of the Autoscreener/FLIR system will be discussed only.

SCAN CONVERTER

The scan converter selected is the Princeton Electronic Products PEP-400R Video Graphic Storage Terminal. It uses an electrostatic storage tube to store one imagery frame.

The scan converter is controlled by a three position switch on the front panel of the Autoscreener's Control Unit as follows:

- Reread the existing stored frame
- Stop read at the end of current frame
- Read continuously new frames

On command from the Control Unit, the scan converter goes through a sequence of erase, write, delay and read out the stored imagery as discussed in the Raster Format subsection.

During the write cycle, two successive frames are averaged at the rate of 30 frames per second. The averaging improves the signal-to-noise ratio for a scene that does not change rapidly. If the sensor moves rapidly with respect to the object (e.g., the sensor is panning the scene), the image

may be blurred which can counterbalance the signal-to-noise improvement achieved by the two frame averaging.

During the readout cycle, the stored image is read out at a rate that can vary from 400 to 4000 microseconds per scan line. Presently, the scan converter is set to read 525 scan lines at a rate of one scan line per millisecond. The imagery read out from the scan converter is fed through Interface #2 to the Autoscreener's Control Unit where it is processed one scan line at a time.

Raster Format

The write (input) raster is the standard TV raster of 525 lines, 30 frames per second, two to one interlaced. The read (output) raster is a slow scan of one field, 512 lines, approximately 1.0 second per frame, with the horizontal scan rate adjustable from 400 to 4000 microseconds per line, and with "on demand" line-by-line scan readout on receipt of the computer's "calculation complete" signal.

Figure 5 shows the scan converter read and write raster formats. The write raster format is the standard EIA TV format. As shown in Figure 5, every other line in one TV frame is written in one field. Time is then allowed for vertical retrace with the alternate in-between scan lines then being written in a second field. The total stored picture in one 525 line TV frame is 485 active lines.

The stored picture is read out completely in just one field scan, using a 512 line raster. For MMO symbol marking purposes, the 512 line raster is

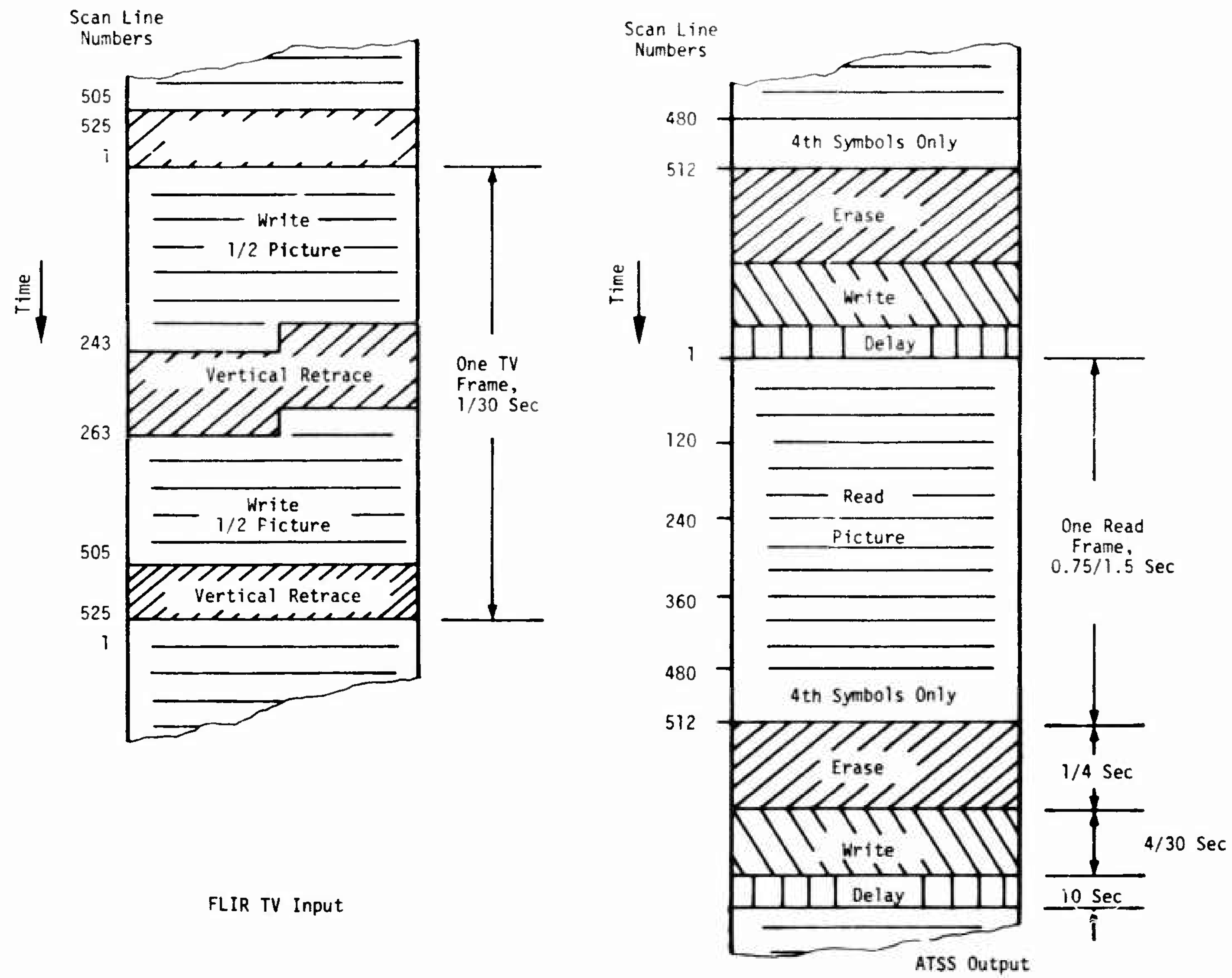

Figure 5. Scan Converter Write and Read Raster Formats

divided into 5 horizontal sector rows. The first 480 lines are divided into 4 groups of 120 lines each. The 5th group of 32 lines (lines 481-512) are only used to provide display space for the MMO symbols from the 4th group of scan lines (lines 361-480).

When stopped, the Autoscreener/FLIR system normally sits at the end of the read frame. The scan converter normally sits in its read mode. To read a new frame of imagery, an erase pulse is sent to both the Autoscreener displays and the scan converter to erase the existing frames. The double erase cycle lasts 1/4 second on the Autoscreener displays and 1/15 second on the scan converter. After erase, the scan converter automatically writes in a new frame and then switches into its read mode after a delay of 10 microseconds. This delay allows the voltage stabilization in the electrostatic storage tube. The read (output) raster reads out the stored image "on demand" only; that is, it waits until the computer has finished processing the data from the previous scan line before reading out the next scan line. When the computer has finished processing the data from a given scan line, it sends a "calculation complete" pulse to the read (output) raster generator. The first scan line in the read (output) raster is started by the read mode signal from the scan converter. Succeeding scan lines are started by the "calculation complete" pulse from the computer. To reread the currently stored frame of imagery, an erase pulse is sent only to the Autoscreener displays and not to the scan converter. The end of the display erase pulse initiates the first read scan line, and the succeeding scan lines are initiated "on demand" from the computer's "calculation complete" signal.

For convenience in testing the read raster, there is a "test-operate" switch on the front of the Autoscreener Control Unit that bypasses both the "on demand" computer interlock and the read mode (raster start) signal from the scan converter. With the switch in the "test" position, the Control Unit will read video out of the scan converter even with the computer shut down or disconnected. If the scan converter is also shut down or disconnected, the read raster will still run, permitting it to be checked out independently without the necessity of having either the scan converter or the computer operating or connected.

To accommodate fast moving video input imagery, it may be desirable to store and read only a single field of video imagery rather than a complete frame or multiple superimposed frames. The scan converter can be set to store only a single field of 242 1/2 lines. The read (output) raster can be changed to read out only 256 lines per frame, instead of 512, by means of a simple jumper change on the raster card.

CONTROL UNIT

The control unit contains the analog/digital circuitry to extract the primitive or first-level features (high and low contrast brightness, edge, step, hot spot, etc.) and to generate the raster for the Visicorder, first-level and output displays.

The details of the theory of operation of the Control Unit are discussed in Volume 1 - System Operation and Maintenance. However, the generation of the first-level features, candidate intervals, and objects associated with the Autoscreener/FLIR system will be discussed next.

Brightness Feature

Two threshold comparators are presently used. One is set high relative to the background and compares the readout video for hot objects and the other is set low for cold objects.

The thresholds V_1, V_2 are set by the operator, and if the video exceeds them, the brightness features B_1, B_2 have a high-voltage output corresponding to logic 1. Otherwise they have a low-voltage output corresponding to logic 0. This is shown in Figure 6. The time, during which the logic state "1" is on, is measured by counting a 2 MHz clock and storing the count in a shift register. This represents the brightness feature over one interval. The brightness features B_1, B_2 are delayed by 16 microseconds to bring them in synchronization with the step feature.

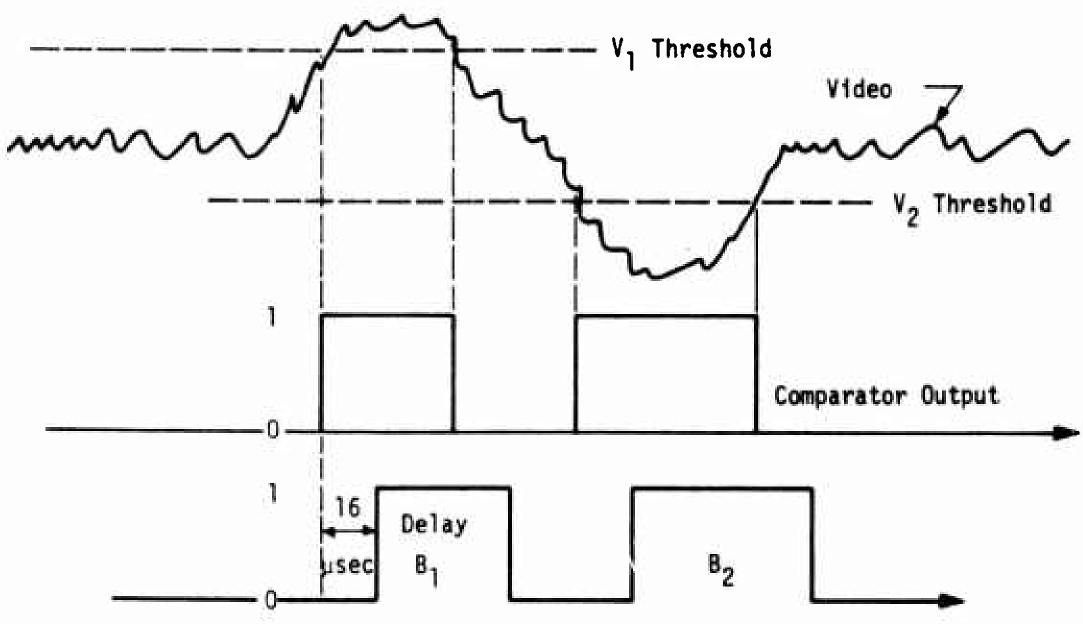

Figure 6. High Contrast Hot-Cold Brightness Feature

Step Feature

The step feature is used instead of the edge feature. The reason for this is that the edge averaging window is too short to process the video signal which is stretched out by a factor of 15.

The step filter is presented in Figure 7. The input signal is delayed (D) and subtracted from the present input to generate the output $S_1(t)$ as shown in Figure 8. The difference (Figure 8c) generates positive and negative steps which are compared with thresholds $\pm V_8$. If the step is greater than $+V_8$, a high-voltage output corresponding to logic 1 is generated; and similarly if the step is less than $-V_8$, a high-voltage output corresponding to logic 1 is generated. Otherwise they have a low-voltage output corresponding to logic 0, as shown in Figures 8d and 8e. The signals $S_2(t)$ and $S_2'(t)$ are averaged over a window and compared with threshold W_1 as shown in Figures 8f and 8g, resulting in signals $S_4(t)$ and $S_4'(t)$ shown in Figures 8h and 8i.

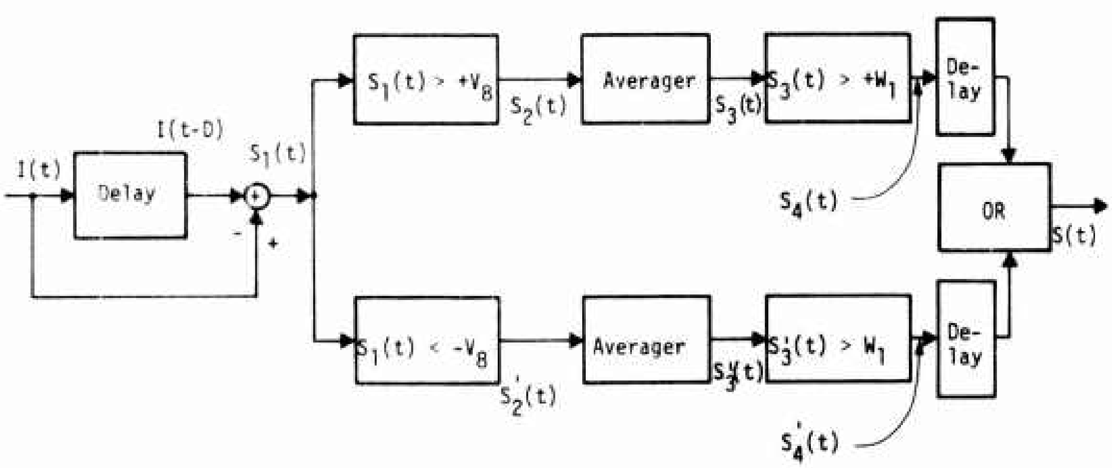

Figure 7. Step Filter

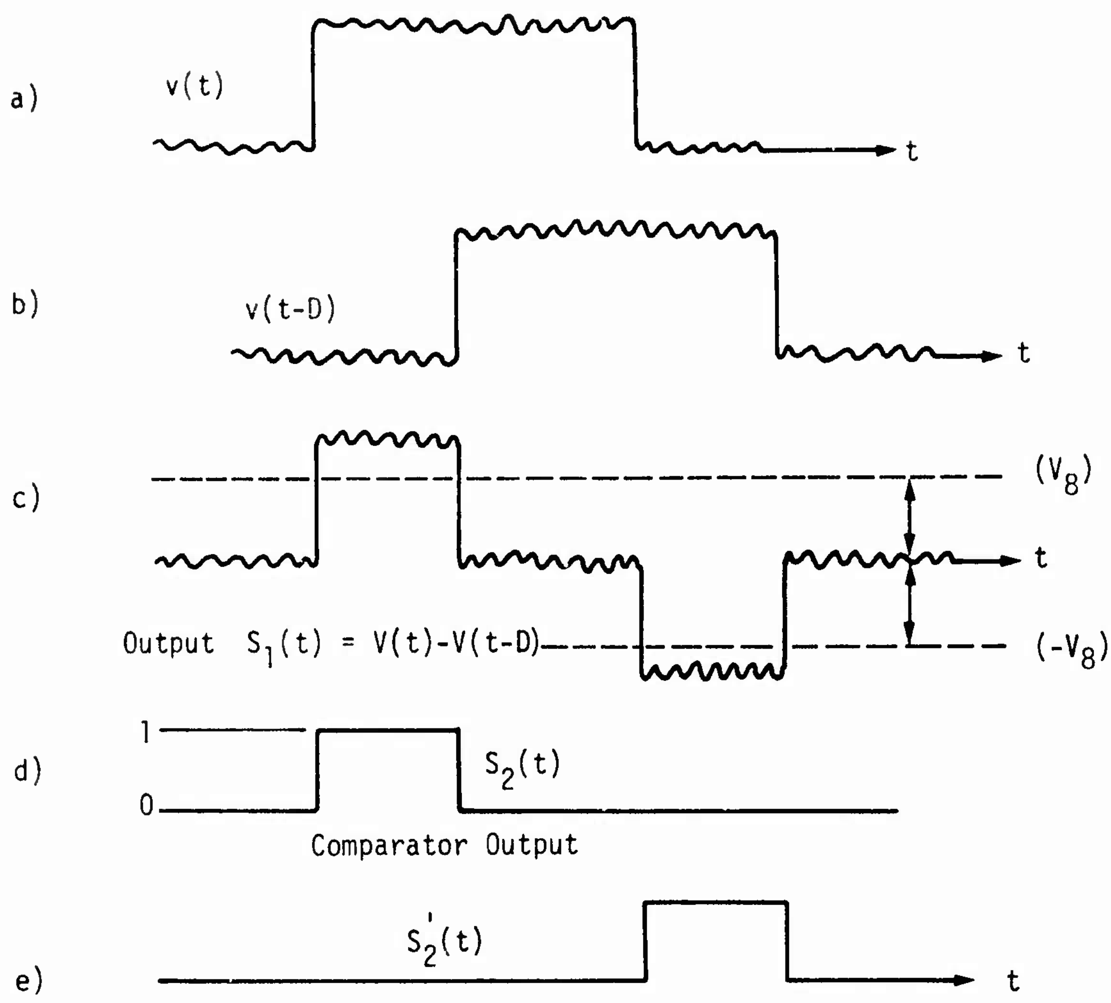

Figure 8. Step Feature Filter Output

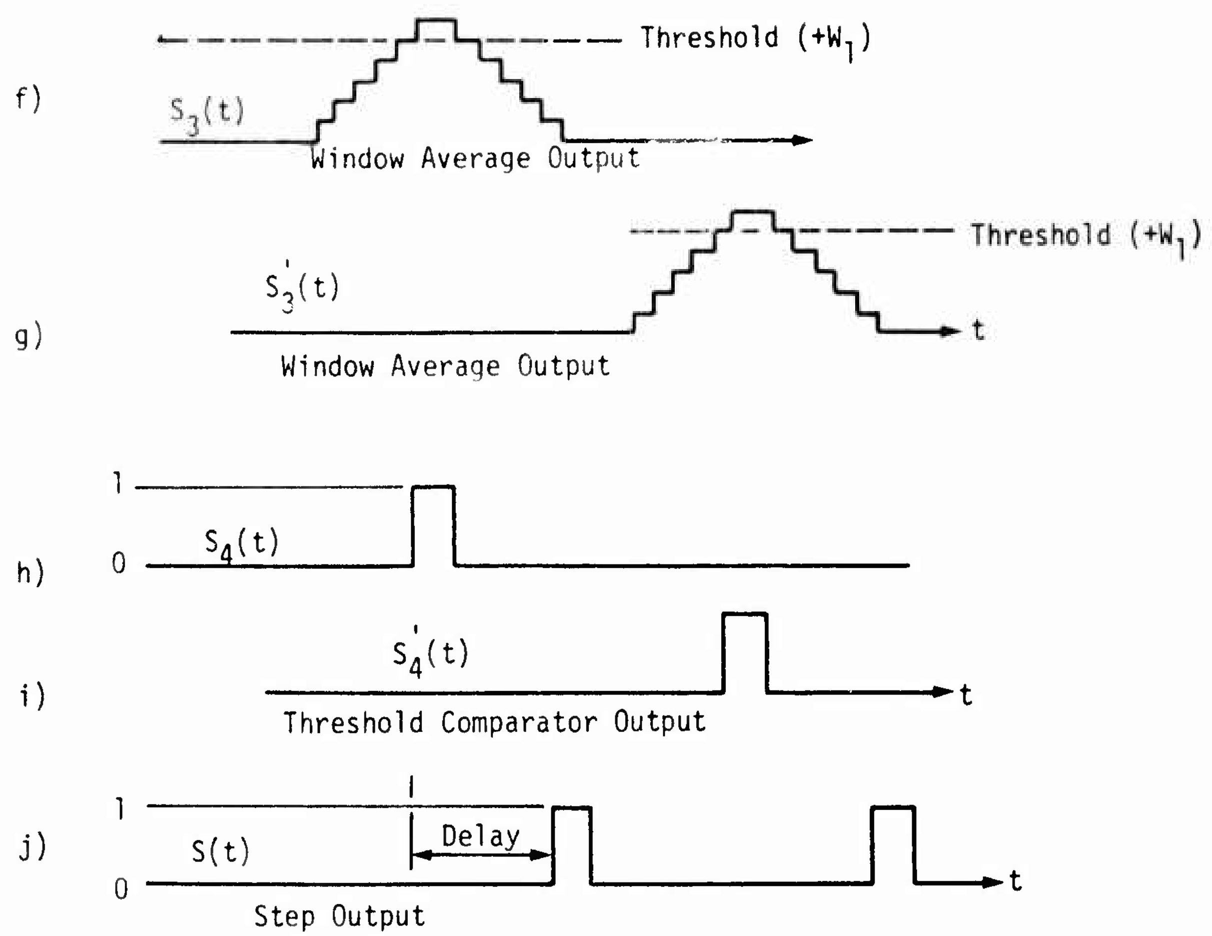

Figure 8. Step Feature Filter Output (concluded)

The last two outputs are ORed and delayed for synchronization and thus generate the step feature S(t) shown in Figure 8j. The time interval during which S(t) = 1 is counted at the closk rate of 2 MHz and stored in a counter. The accumulation of the counter at the completion of an object represents the step (edge) count feature. The signal S(t) is an input to the START ans STOP criteria in initiating a candidate interval.

DIGITAL PROCESSOR

The digital processor is described in detail in Volume 1 - System Operation and Maintenance. The START and STOP criteria will be discussed since they were modified for the Autoscreener/FLIR system.

Interval Detect

The candidate interval detect logic ANDs the brightness feature and the step feature. If $B_1 \cdot S = 1$ in M_1 clock pulses out of N_1 successive clock pulses, the START criterion is satisfied, and a candidate interval ($F_1 = 1$) is initiated at the clock rate. Its width is counted at the clock rate of 2 MHz until the STOP criterion is satisfied. The STOP criterion initiates the end of a candidate interval if, in M_2 clock pulses in N_2 successive clock pulses, the condition $\overline{B}_1 \cdot \overline{S} = 1$ is true. This is shown in Figure 9.

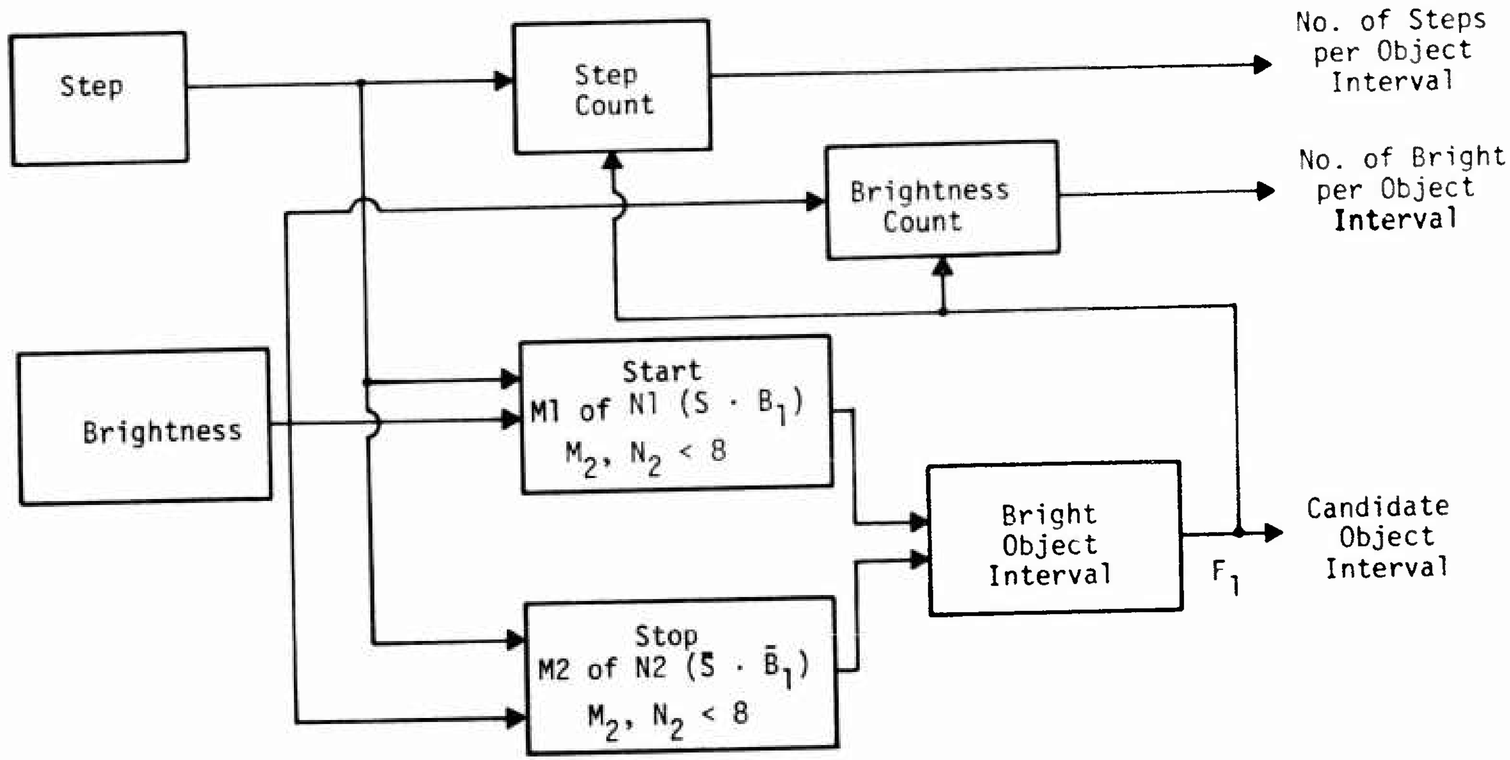

Figure 9. Start and Stop Criteria for Candidate Object Interval

SECTION 4

HARDWARE AND SOFTWARE MODIFICATIONS

The first objective of the Autoscreener/FLIR program was to modify the existing Autoscreener hardware in order to make it compatible with the FLIR system. This objective was met by incorporating an electrostatic scan converter, three interfaces and some software modifications. The hardware and software modifications are presented in this section.

HARDWARE MODIFICATIONS

The original Autoscreener hardware were modified as follows:

- Deletions
  - 201 computer
  - Core memory for 201 computer
  - Krohn-Hite 5100A voltage control oscillator
- Additions
  - PEP-400R scan converter
  - Sony AV-3600 video tape recorder
  - Conrac DZA monitor
  - Input symbol mixing circuitry
  - Audio alarm, activated by MMO symbols

- Changes
    - Parallel reading of the step (edge) and brite counters
    - New raster and symbol generator for the output display and Visicorder
    - Digital processor

The additions and changes are discussed next.

Scan Converter

The scan converter is a low cost solution to handling the higher video data rate from a FLIR sensor. The use of a scan converter is interim only. In a production model of the Autoscreener, its front end circuits would be redesigned to handle the higher video bandwidth directly, without going through a scan converter.

The scan converter selected is the Princeton Electronic Products No. 400R Video Graphic Storage Terminal. This is an electrostatic storage type, which is lower in cost than the magnetic disk type as manufactured by Arvin. It is a single ended model, which means that you can record a video frame and then read it out, but you cannot read and write a video frame simultaneously. It is very well designed and built, and uses relatively simple circuitry. Its only apparent drawback is that part of its logic circuitry operates at -4V, instead of all of it being at +5V (TTL).

The advantages of electrostatic storage type scan converters are the low cost, the variable readout rate and the readout on demand capability.

The disadvantages are the limited dynamic range and the possibility of permanent burn on the storage screen surface. This occurs when the write or read electron beam stops at a given point on the storage surface, instead of continuing the scan. With the PEP-400, a burn will occur if the beam stops for more than 15 seconds in the write mode, or for more than a couple of minutes in the read mode.

The control signals required and provided by the scan converter are listed in Figure 10. Applying three external jumpers between six of these external signals, as shown in Figure 10, will automatically step the scan converter through the erase-write-read sequence every time it receives an erase pulse. The scan converter contains the write raster generator and a sync stripper for stripping off the sync pulses of the video input signal. It has a DC-coupled video write amplifier, and an AC-coupled video read amplifier. The converter normally sets in its read mode. When first turned on, it takes about 15 minutes for the read video signal to become fully stabilized in amplitude.

Several frames can be averaged on the storage surface. This is advantageous in cancelling out random noise in the video input signal. The number of averaged frames is easily adjusted by means of a jumper on an internal logic board from one to eight fields (1/2 to 4 frames).

The scan converter is controlled by a three position switch on the front panel of Autoscreener's Control Unit. The three switch positions are:

1) Reread the existing stored frame.
2) Stop read at the end of current frame.
3) Read continuous new frames.

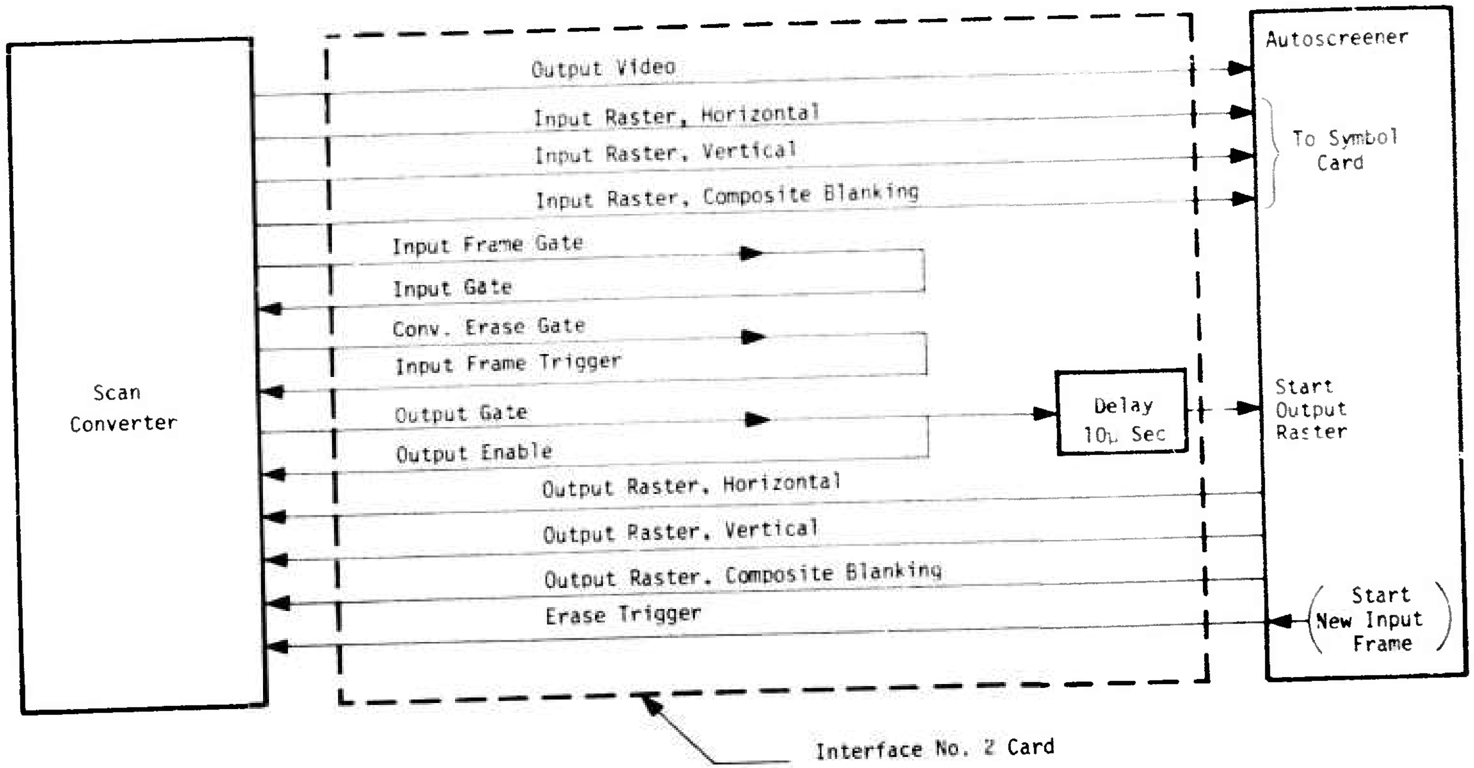

Figure 10. Scan Converter Control Signals

Read (Output) Raster Generator

The read (output) raster generator for the scan converter consists of two cards, #2B and #8, in the Autoscreener Control Unit.

The read (output) raster puts out one scan line at a time and then waits for the "calculation complete" "CALCPT" signal from the computer saying that it has finished computing the data from the last scan line before it puts out the next scan line. The first scan line in the raster is started by the read signal from the scan converter. Succeeding scan lines are started by the "CALCPT" signal from the computer.

Figure 11 shows a schematic of the read (output) raster's horizontal ramp generator. The horizontal ramp is generated by integrating a DC voltage that comes from a front panel pot. All analog integrators have a DC drift problem. The DC drift in this integrator is eliminated by a feedback loop during the wait intervals between scan lines. This maintains a constant starting voltage at the start of each ramp to insure that each scan line starts at the same position on the scan converter's storage surface. The horizontal scan rate is adjustable by varying the DC input voltage to the integrator by means of the front panel V/H pot on the Control Unit. This is mainly to accommodate the existing fixed time constants in Autoscreener's feature extraction circuits.

A schematic of the read (output) raster's vertical ramp generator is shown in Figure 12. The vertical ramp is generated by counting the horizontal scan lines and using a D/A converter to generate the vertical ramp. The scan line counter's output is also used to define the end of the read raster

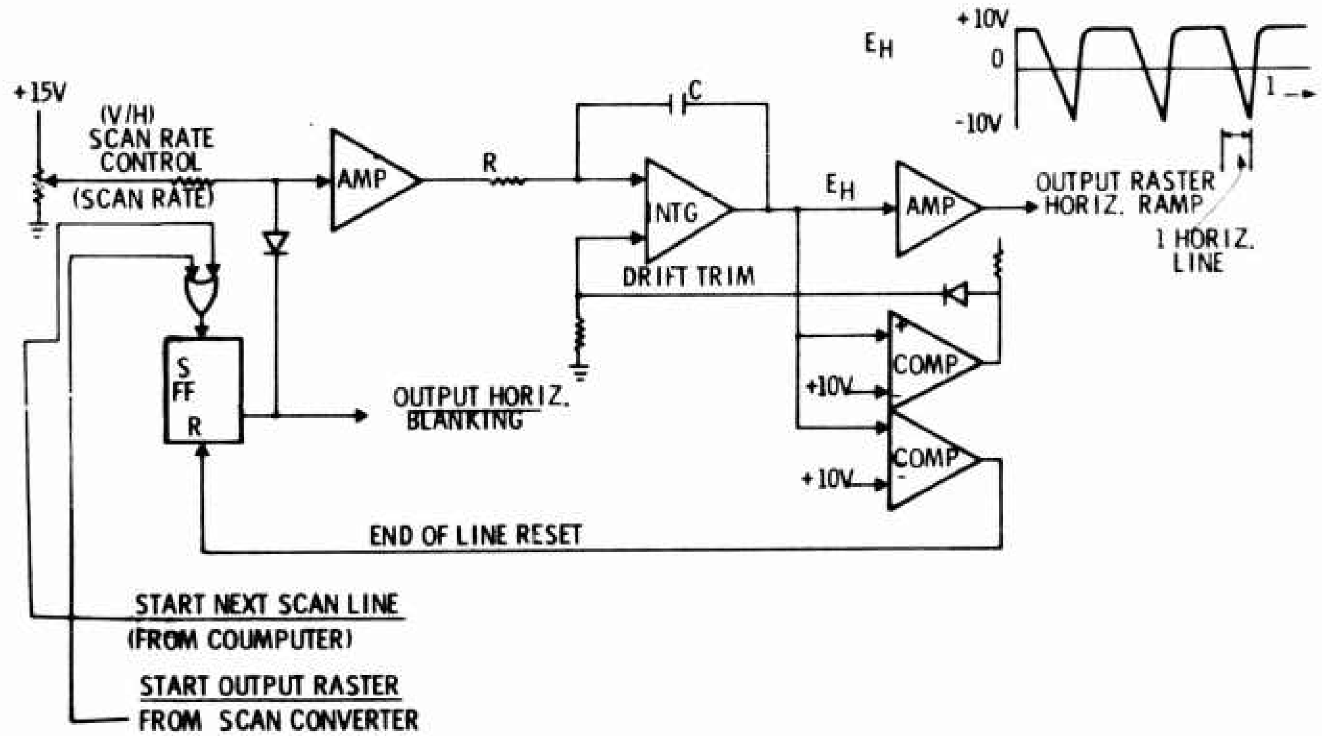

Figure 11. #2B$_1$ Output Raster, Horizontal Ramp

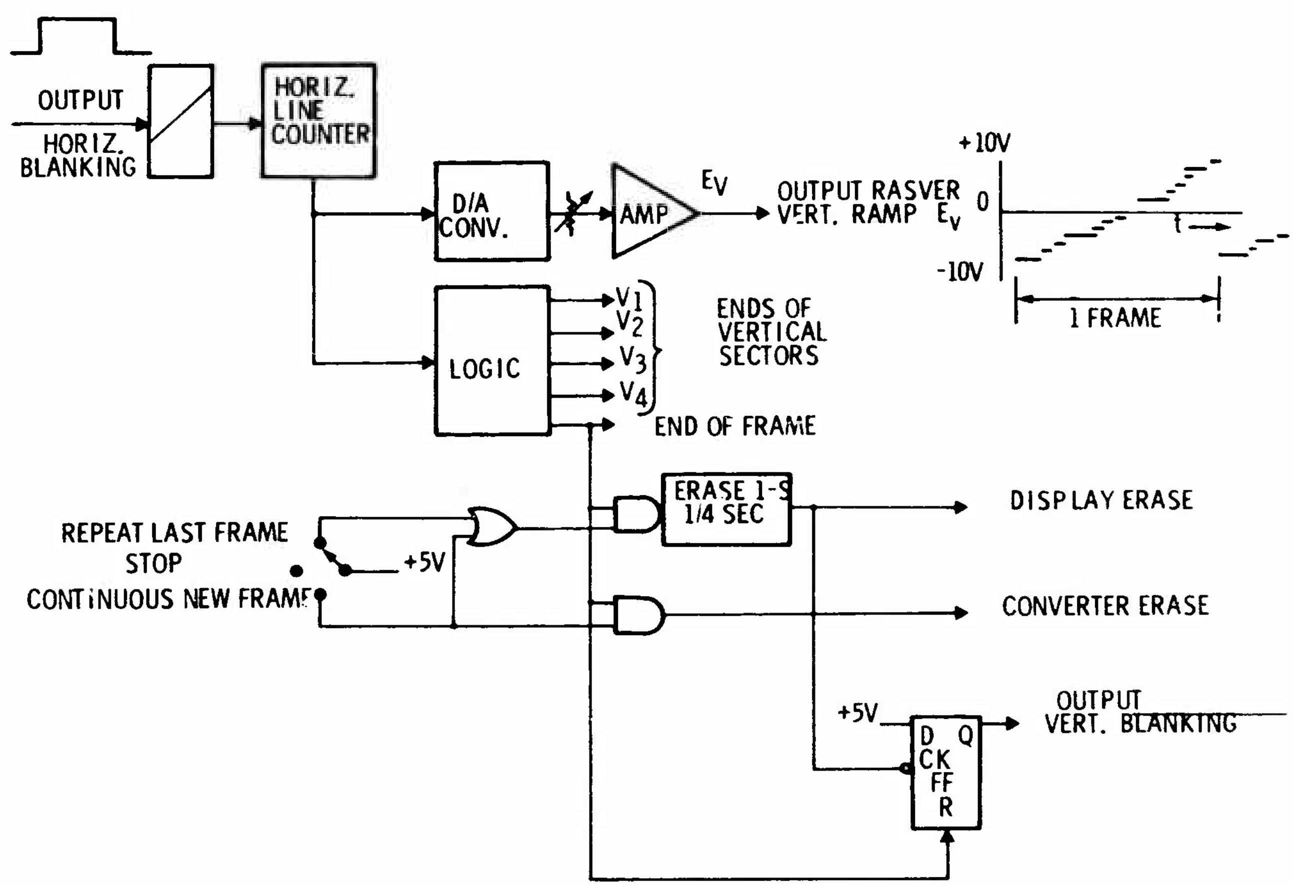

Figure 12. #2B_2 Output Raster, Vertical Ramp

and the four ends of the scoring rows, which then generate five signals at the ends of the 120, 240, 360, 480, and 512th lines, respectively. The 512th line defines the end of the readout raster.

Output Symbol Generator

There are 16 locations on the raster display (output display and Visicorder) for the MMO symbols (Figure 4). Their horizontal location is determined in the software where the width of the first line for each frame is counted at the 2 MHz clock rate. From this count, the 1/4, 1/2, and 3/4 positions of each scan line are determined. A schematic of the output symbol generator is shown in Figure 13. The vertical location of the output symbols is determined by the end-of-sector-row pulses, V1-V4. At the end of each horizontal sector row, the computer is asked by the end of sector pulses V1-V4 whether it has found any MMOs. If the computer has found any, it sends this information serially to the raster generator where it is stored in four parallel flip flops, H1-H4. These outputs are ANDed with the output horizontal ramp comparators. The comparator outputs are ORed and ANDed with the counter of the vertical symbol height to initiate a symbol.

A fixed symbol size is wanted on the display. Since the read (output) raster's horizontal scan rate is variable, the width of each symbol bar is determined by integrating a variable DC voltage obtained from the same DC control voltage used to vary the horizontal scan rate. This voltage is integrated up and down between two fixed voltage limits three times to get a complete symbol width of three dark bars and three bright bars. The time required to integrate between these two fixed voltage limits determines the width of each symbol bar.

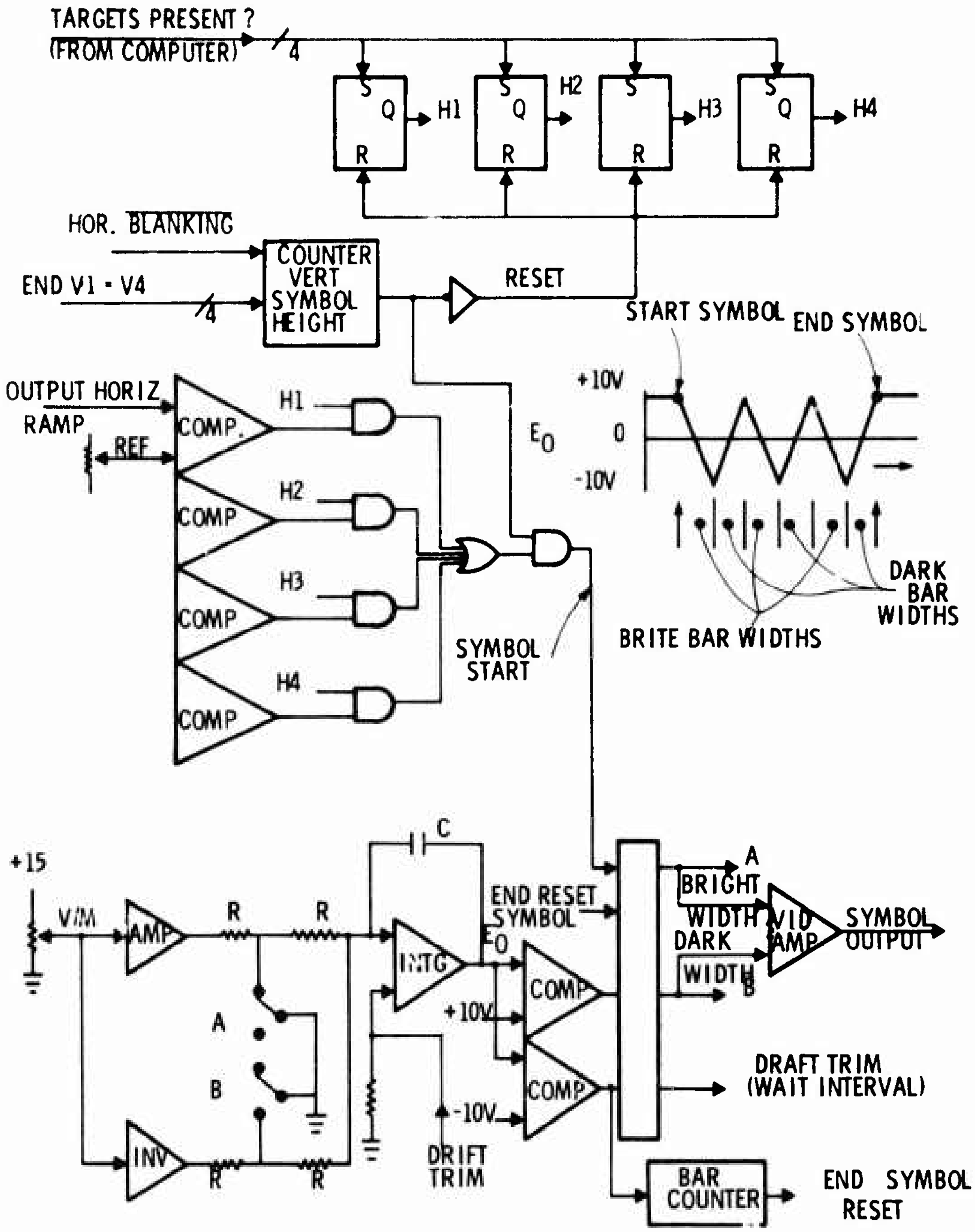

Figure 13. #4 - Output Symbol Generator

A fixed vertical symbol height is obtained by counting 25 horizontal scan lines with a counter. The symbol height is thus a fixed number of horizontal scan lines in height. The total symbol width on the display is determined by a counter which counts the number of bright bars in the symbol and shuts the integrator off at the end of the third dark bar, ending the symbol.

Input Symbol Generator

The MMO symbol is generated by the Autoscreener in the read (output) raster. To display the symbols on the FLIR monitor, the location of the MMO symbols have to be transferred from the read (output) raster, which lasts approximately 1 second, to the input raster, which lasts 1/30 of a second. The approach taken is to store the MMO symbols, as they are generated, in a 16 bit memory (arranged 4 by 4) and write them on the input raster repeatedly. A schematic of the input symbol generator circuitry is shown in Figure 14. The 16 memory locations represent the 16 possible symbol locations on the raster display.

The locations of the MMO symbols in the input (write) raster are determined by four horizontal and vertical reference voltages, which are compared to the horizontal and vertical deflection ramps of the input raster. These horizontal and vertical ramp signals are obtained from the scan converter's write raster. Since the 16 possible MMO symbols are stored in a memory with simultaneous read/write capability, they can be read out simultaneously and displayed in the input raster at the same time that they are generated and displayed in the output raster.

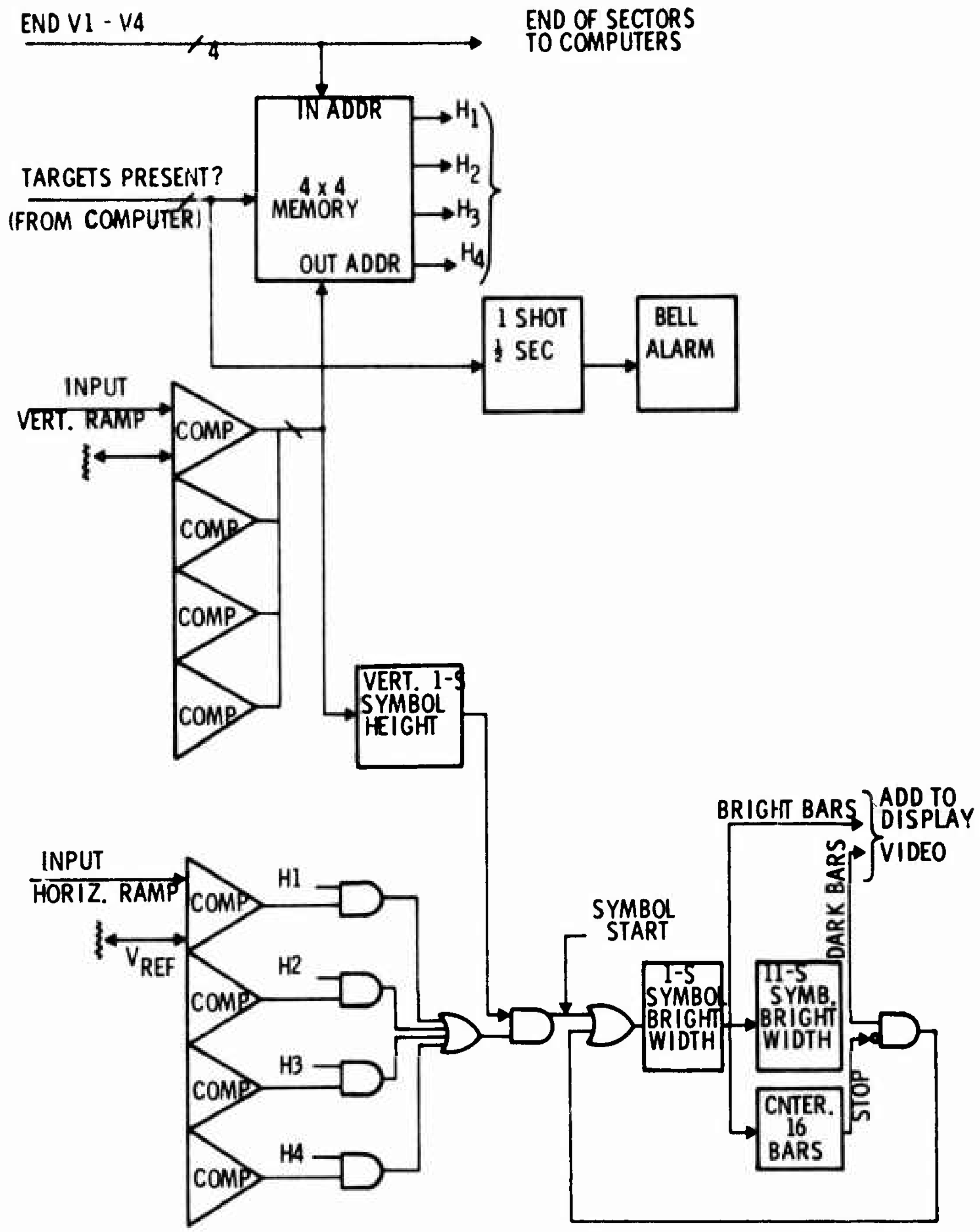

Figure 14. Interface #3 Input Symbol Generator

Once displayed, an MMO input symbol stays written on the FLIR monitor screen until the Autoscreener processes another imagery frame and decides that an MMO symbol no longer belongs in that sector.

Raster timing is fixed in the input raster. Symbol width and height can therefore be controlled most simply by means of one shots.

Audio Alarm Generator

An audio alarm was added to the Autoscreener hardware. The audio alarm goes on for 1/4 second for every MMO in a horizontal sector. An On/Off switch is available to turn the audio alarm off.

Digital Processor

The digital processor hardware was modified in order to correct for the "compute shadow," to eliminate the high and low contrast conflict and substitute the step for the edge in the interval extraction. These modifications are discussed below.

Compute Shadow--There is a hardware anomaly with the original hardware called "compute shadow" which essentially blinds the system for 50 microseconds after the detection of any candidate object interval. This compute shadow is always 50 microseconds and it affected the operation of the Autoscreener with the AAS-27 scanner only by 2.5 percent since the active scan line was 2000 microseconds. The compute shadow affected the operation of the Autoscreener with the FLIR sensor because the active FLIR scan line is 63.5 microseconds.

The effect of the compute shadow was minimized by reading out the stored image at a slower rate. This readout rate is variable from 500 microseconds to several milliseconds.

The readout scan duration should be as long as possible and at the same time not exceed an upper limit. The upper limit is 1.8 milliseconds per scan line and corresponds to a stretching of the FLIR scan line by a factor of 30. This stretching causes the extracted objects to be very large which causes the feature counters to overflow. At the same time noise impulses stretched out 30 times begin to look very much like objects.

The current system is set to read out and process one scan line per millisecond and is working rather well, although it stretches out the imagery by a factor of 15.

High and Low Contrast Conflict

It was discovered, during this program, that the high contrast circuit was interfering with the low contrast circuit. Any well-defined low contrast object has steep enough edges to generate an edge as well as a step signal. The edge signal turns on the high contrast interval signal (F_1) which suppresses the low contrast signal (F_2). The high contrast interval is very short and hence ignored and the low contrast interval was never generated. Thus, the low contrast object was not extracted.

Working with the noisy FLIR imagery, it was difficult to set the six intensity thresholds meaningfully. The processing worked best with two thresholds: the high contrast HI and the low contrast LO thresholds. So it was decided to use only the high contrast circuit with the ANDed START criterion.

In addition, the averaging window of the edge filter was too short to process the stretched signals. The step filter has much longer averaging window than the edge filter and was used rather than the edge filter. The current system ORs the two step filter outputs (positive and negative) and ANDs it with the high contrast bright for the START criterion. Similarly, the high contrast bright and step outputs are used for the STOP criterion.

SOFTWARE MODIFICATIONS

The Autoscreener on-line and off-line software were modified. The modifications are discussed next.

On-Line Software

During the processing of FLIR imagery with the Autoscreener hardware, it was discovered that candidate objects, which were represented well on the first-level display, were ignored by the system. These objects were lost in the software tracking bin maintenance processing.

The capability to look closely at the bin maintenance processing did not exist at the time. The on-line diagnostic routine had to be modified to generate sufficiently detailed data to recreate a blow by blow picture of what was occuring in the software.

The results of this detailed study indicated that the bin maintenance philosophy was questionable. On the original Autoscreener system with the AAS-27 scanner, the quality of the imagery was very high and there was a fear that nine tracking bins were not enough. So a philosophy of making it very

hard for an object to get and keep a tracking bin was built into the maintenance software. This worked well with high quality imagery, but in low quality FLIR imagery, objects could not keep a bin over several scan lines and were effectively ignored. Furthermore it was discovered that the nine bins were never all filled and they did not form a system bottleneck.

The operational routine was modified to make it easy instead of difficult for an object to get and keep a tracking bin. The effect was quite dramatic because, as it turns out, this stingy bin philosophy had been aggravating some other problems. This was the single most significant problem contributing to poor operation with FLIR imagery.

With the AAS-27 scanner, there was a scaling function dependent on the ratio of the aircraft velocity to its altitude. This scaling function is meaningless to the operation of the Autoscreener with FLIR and was removed from the operational routine.

Off-Line Software

An off-line subroutine was generated to format and analyze the data generated by the revised diagnostic routine. It is called the "Bin Maintenance Analysis Routine" and runs on the XDS-9300 computer.

The final feature scaling from the training sequence was removed.

The off-line software was modified to account for the FLIR imagery format characteristics. The FLIR imagery has constant length (525 lines) and variable scan line width while the AAS-27 scanner had constant width (4000 pels) and variable length (continuous).

SECTION 5

AUTOSCREENER/FLIR PERFORMANCE EVALUATION

The performance of the Autoscreener/FLIR system to detect man-made objects was evaluated utilizing about 350 frames of FLIR video imagery. The performance in terms of probability of detection and false alarm as well as the features and classifier training and testing are discussed in this section.

FEATURES

The original features of the Autoscreener were used for this system and are presented in Table 1.

TABLE 1. FEATURES

No.	Feature
1.	No. of Scan Lines, L
2.	Area (ΣW_i)
3.	Edge Straightness $(100\Sigma \lvert \Delta X_{i+1} - \Delta X_i \rvert / L)$
4.	Edge Discontinuity $(100 \lvert W_i - W_{i-1} \rvert > 20/L)$
5.	No. of Edges $100\Sigma E_i$
6.	No. of Brights $100 \Sigma B_i$
7.	Max $(\frac{W}{L}, \frac{L}{W})$

Note: W_i = interval width

W = effective width

ΔX = difference in successive mean location

Sixteen representative frames were processed with the Autoscreener hardware. There were 401 candidate objects extracted. Each object is represented by seven numbers corresponding to the seven features. Among the extracted candidate objects, utilizing ground truth, there were 74 man-made objects and 327 nuisances.

Histograms for each feature for the classes of man-made objects and nuisances were determined, plotted and presented in Figures 15 through 21.

Figure 15 indicates that the target length is bimodal with the nuisance length spread throughout the bin range.

Figure 16 indicates that the target area is bimodal with the nuisance length spread through most of the bin range.

Figure 17 indicates that the target edge straightness is unimodal with the nuisance edge straightness spread in three distinct intervals. It appears that this feature discriminates reasonably well between the two classes.

Figure 18 indicates that the target $\frac{L}{W}$ or $\frac{W}{L}$ feature is unimodal with the corresponding nuisance feature spread throughout the available bins.

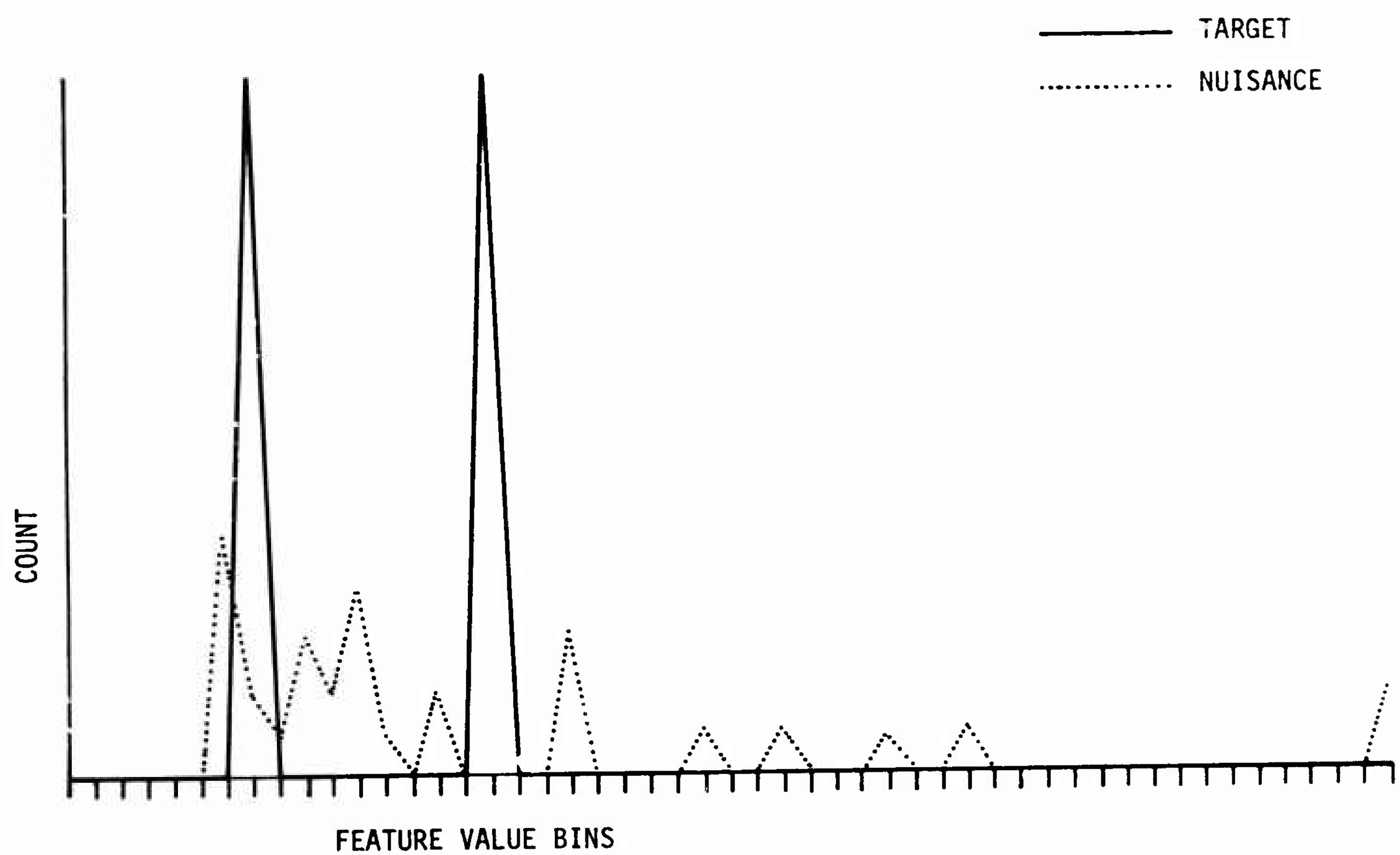

Figure 15. All Targets versus All Nuisances
Feature 1: Length

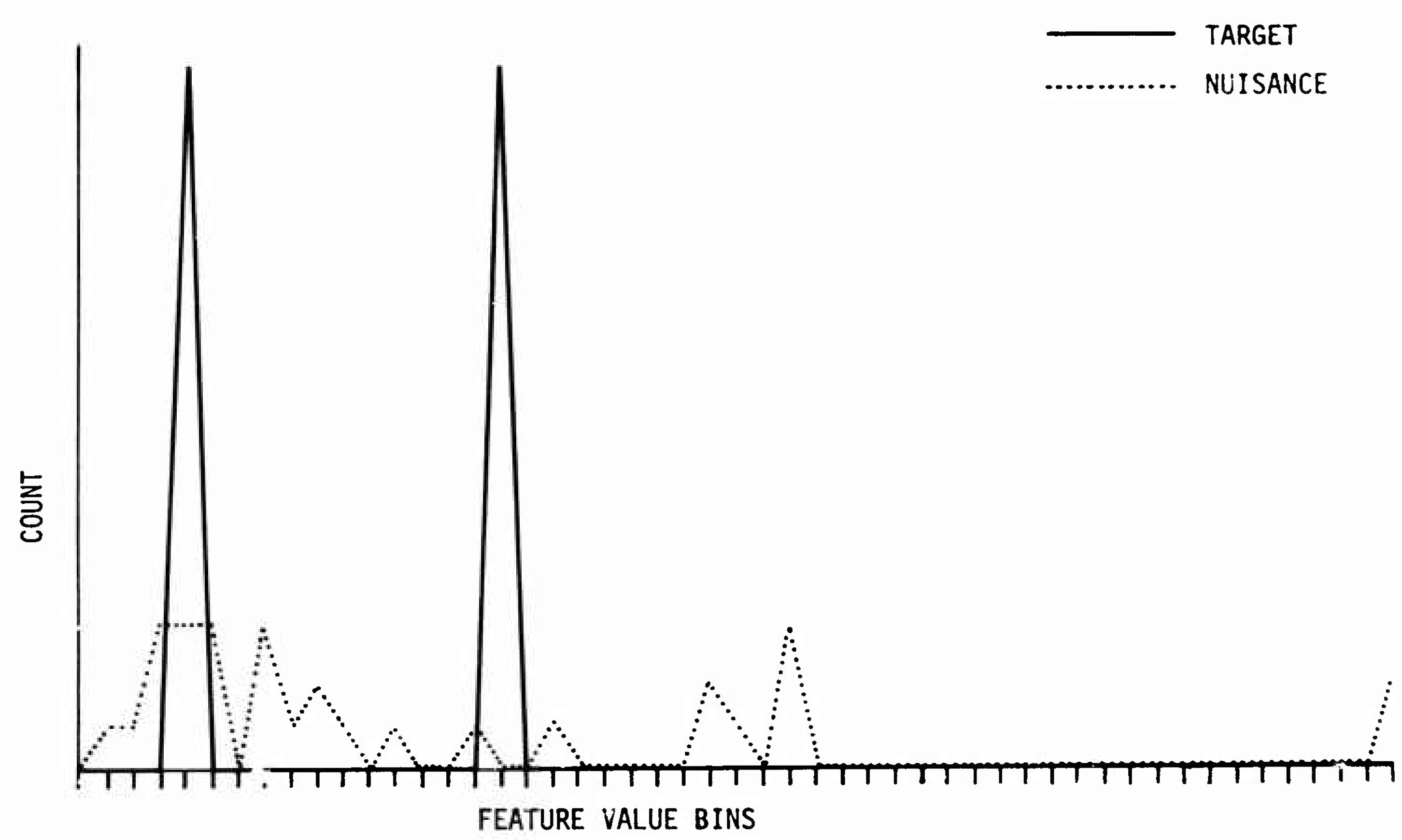

Figure 16. All Targets versus All Nuisances
Feature 2: Area

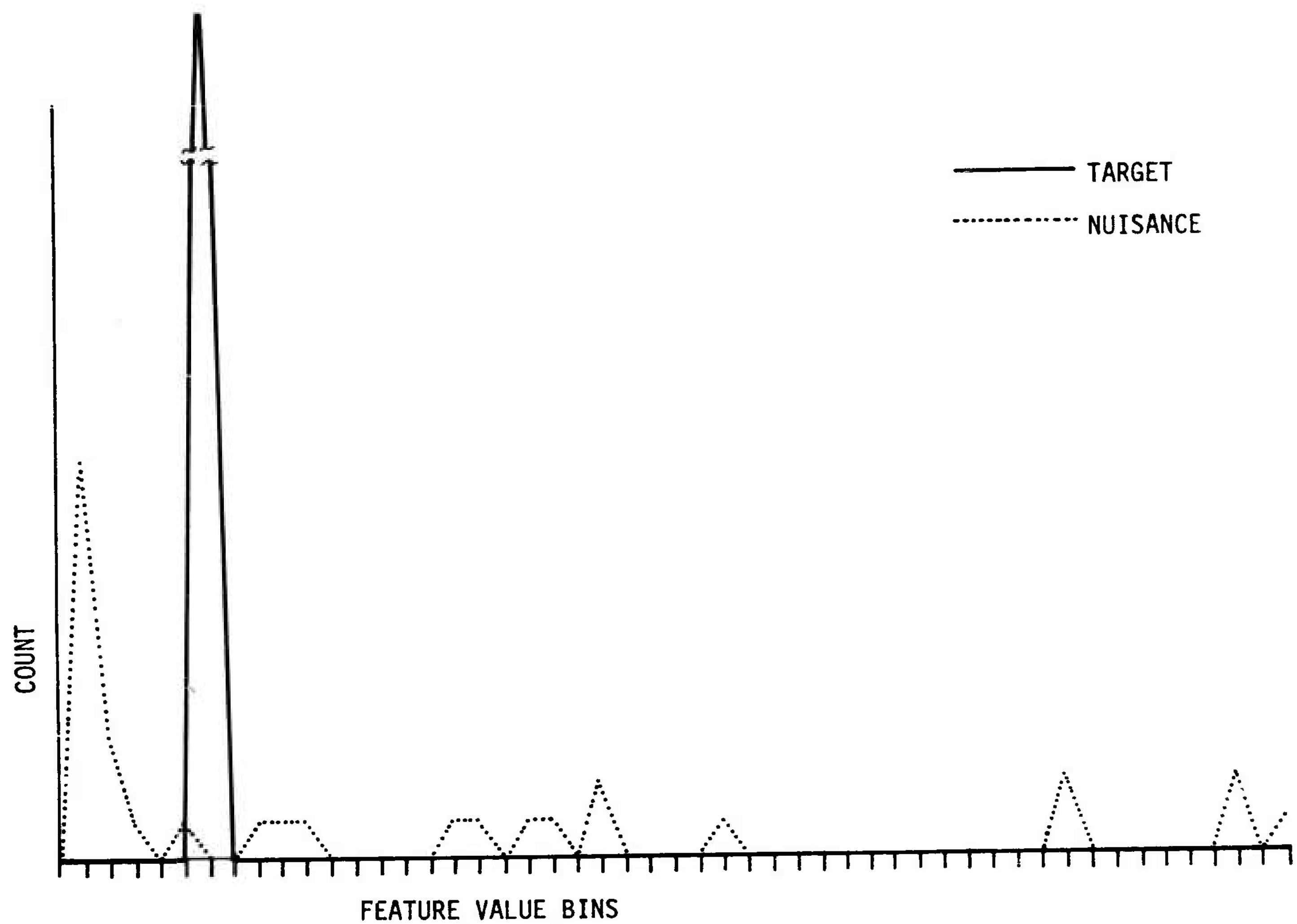

Figure 17. All Targets versus All Nuisances
Feature 3: Straightness

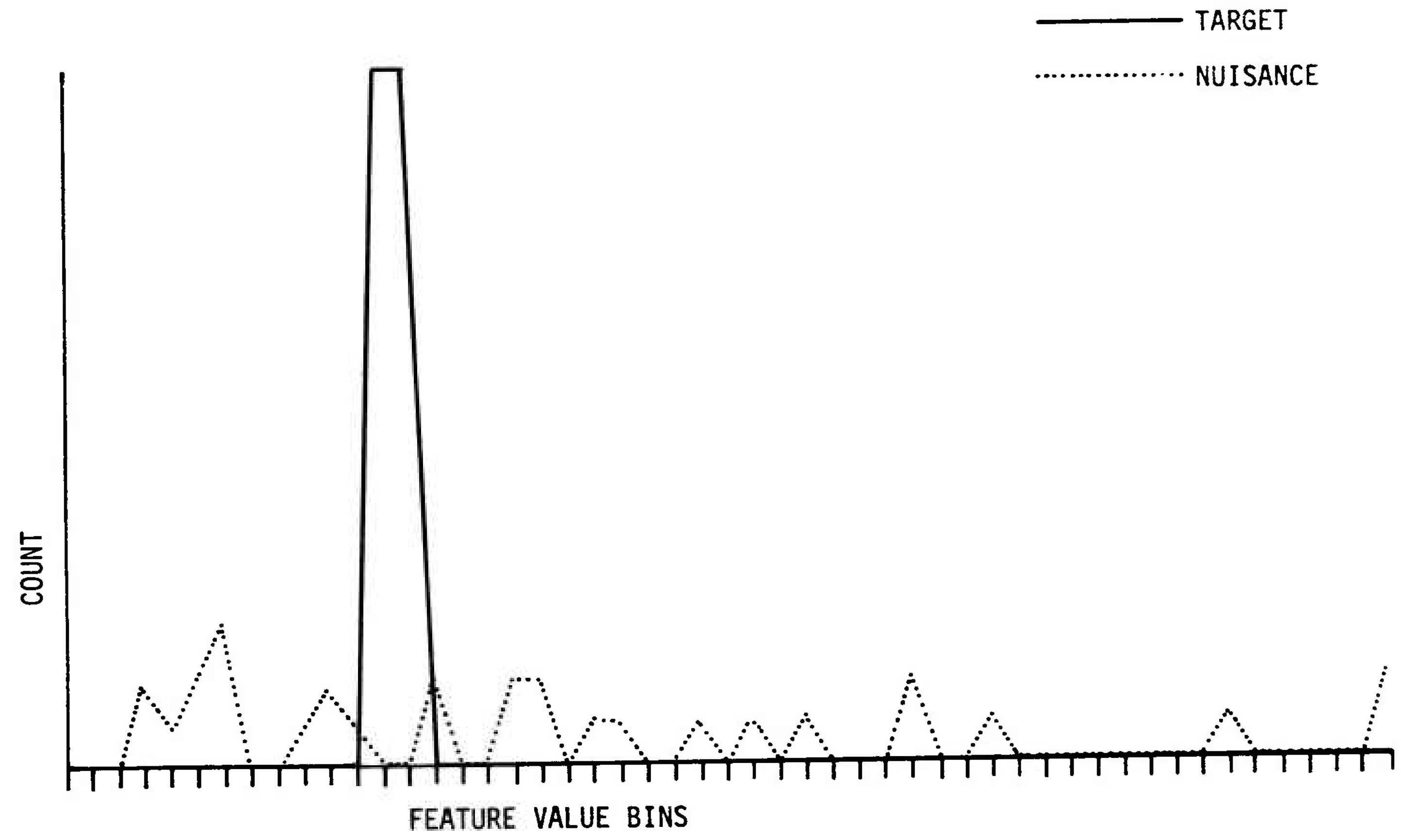

Figure 18. All Targets versus All Nuisances
Feature 4: L/N or N/L

Figure 19 indicates that the target edge discontinuity is unimodal with the nuisance edge discontinuity spread throughout the bins.

Figure 20 indicates that the target edge count is unimodal and separated from the nuisance edge count which is uniformly distributed in the lower bins.

Figure 21 indicates that the target and nuisance brite count have bimodal distribution.

CLASSIFIER STUDY

The classifier study consisted of two tasks. In the first task, we trained the classifier, and in the second, the trained classifier was tested on about 350 FLIR imagery frames.

Classifier Training

The complete procedure for training is described in detail in the program documentation package.* A few aspects are repeated here to facilitate the discussion. As discussed previously, the video signal is processed to extract the first level features, which are combined to extract intervals

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* Ibid

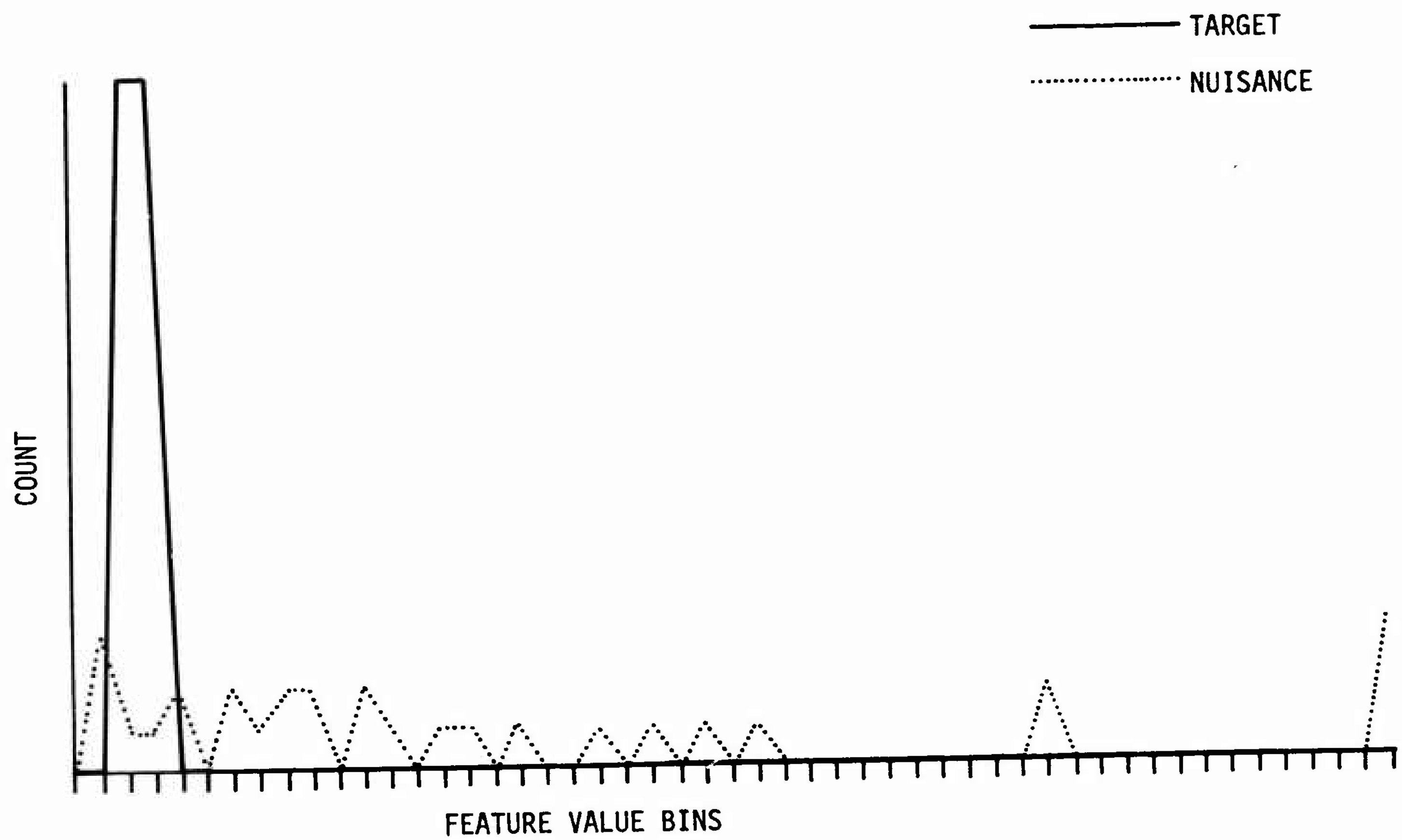

Figure 19. All Targets versus All Nuisances
Feature 5: Edge Discontinuity

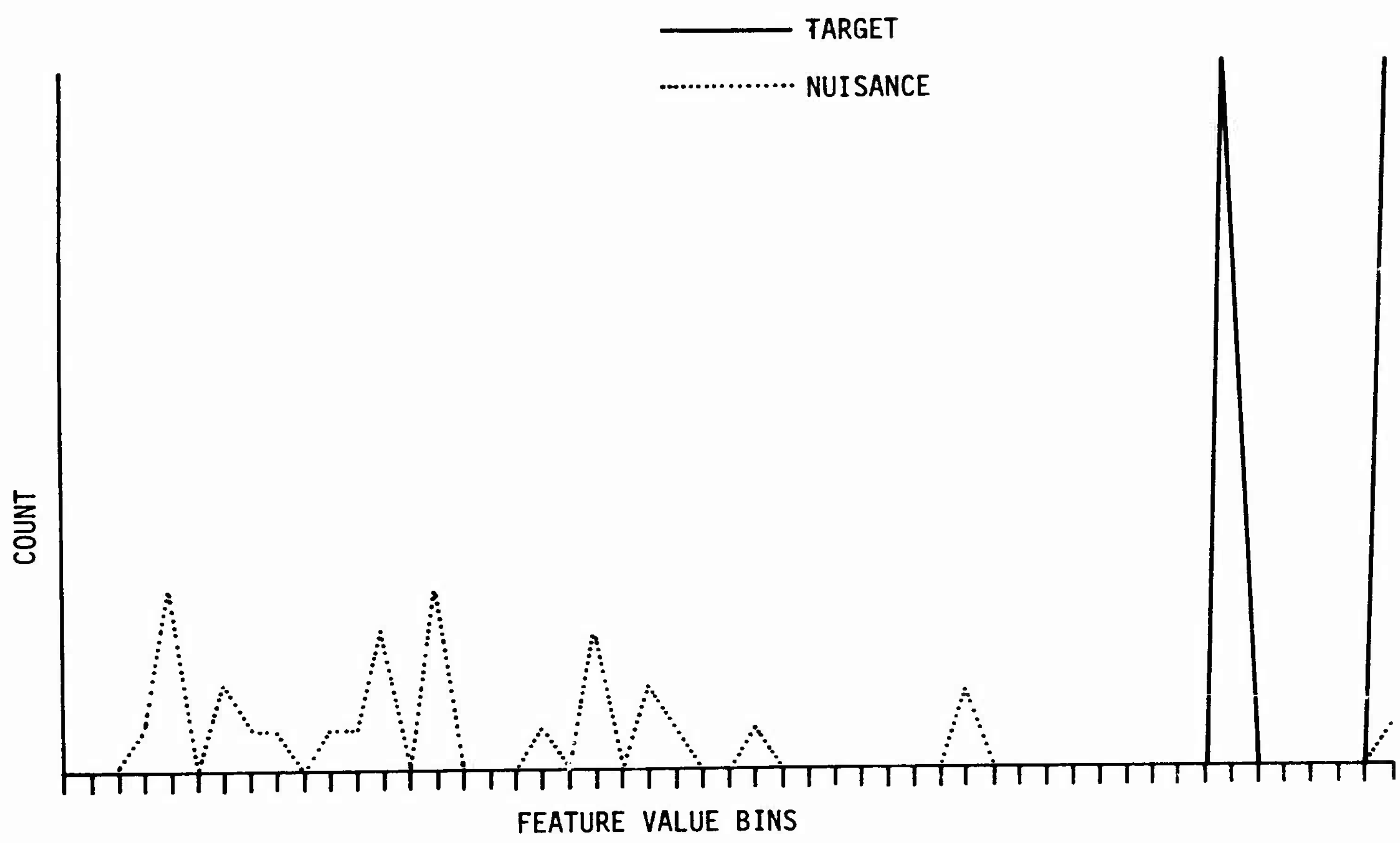

Figure 20. All Targets versus All Nuisances
Feature 6: Edge Count

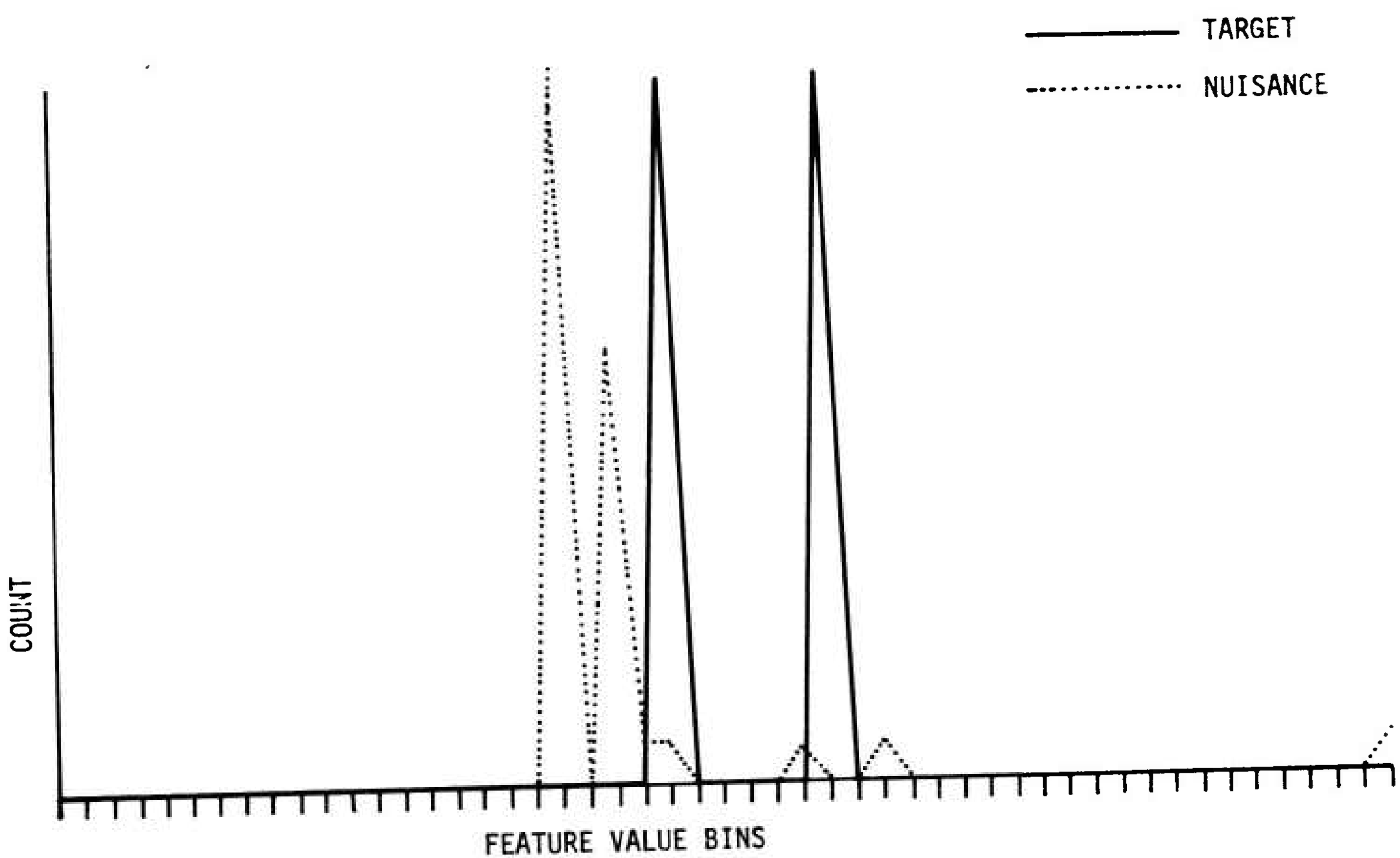

Figure 21. All Targets versus All Nuisances
Feature 7: Brite Count

and then successive intervals map out candidate objects. The information stored for each candidate object is processed to extract the seven features of Table 1. Changing the bright and step thresholds, a new set of features is extracted. The best set of features is the one that separates the two classes during training and results in high probability of detection and low false alarm probability.

The training set of objects and nuisances was extracted from 16 representative frames of data, and using the Autoscreener training subroutine, the training of the classifier was accomplished as described in Section 5 of the final ATSS report.* The extracted candidate object feature values were recorded on digital magnetic tapes. The processed imagery was recorded on Visicorder paper and the video imagery was our ground truth.

In the case of the forward looking IR (FLIR) sensor, the size of man-made objects depends on the range between the sensor and object which in turn depends on the sensor altitude and aspect angle. Because of the object size variability, we decided to design two classifiers for small and large objects. The criterion of this dichotomy is the object area. If the target area is greater than 400 pels, the object is large; otherwise it is small.

The extracted objects were distributed as shown in Table 2.

The classifier was then trained with three and seven features. The results are presented in Table 3.

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* Ibid

TABLE 2. TRAINING OBJECT DISTRIBUTION

	Small	Large
Man-Made Objects	29	45
Nuisance	67	260

TABLE 3. CLASSIFIER TRAINING PROBABILITIES

	Number of Features	
	3	7
Large Objects		
$P_{Detection}$	100%	99%
$P_{False\ Alarm}$	6%	5%
Small Objects		
$P_{Detection}$	97%	100%
$P_{False\ Alarm}$	10%	13%

The seven features were used for testing the classifier on the remaining imagery.

The classifier coefficients for small and large objects are presented in Table 4.

TABLE 4. CLASSIFIER COEFFICIENTS

Feature	Coefficients	
	Small	Large
Length	-0.0235630	-0.004099
Area	0.0077440	-0.000295
Edge Discontinuity	-0.0008410	-0.000209
Edge Straightness	-0.0000285	-0.000050
Edge Count	0.0018310	0.000862
Bright Count	0.0034820	0.001327
$\frac{L}{W}$ or $\frac{W}{L}$	-0.0001420	-0.000039
Constant	0.2057900	0.364370

Classifier Testing

Eleven imagery segments from four half-hour, half-inch video FLIR tapes were recorded on a video tape. The FLIR tapes were recorded during flight tests at A. P. Hill Field by Naval and Honeywell personnel with a Honeywell FLIR. The eleven segments run for about 10 minutes and contain the following:

Segment 1. The aircraft initiates a run at a distance of three to four miles and flies over a track target which is located at the border line between a forest and marsh flat land.

Segment 2. The flight is the same as in Segment 1 but the target is a tank.

Segment 3. The flight is the same as in Segment 2. The tank is hidden in the forest, and as the aircraft closes in, the tank appears on the display.

Segment 4. Similar flight except the target is a vehicle in the middle of a field by a dirt road.

Segment 5. The aircraft flies over several clusters of homes in the country.

Segment 6. This is similar to Segment 5.

Segment 7. This is similar to Segment 5.

Segment 8. This is similar to Segment 5. In this segment there are several black (cold) objects.

Segment 9. The aircraft flies over an area with a very limited number of man-made objects.

Segment 10. This is the longest segment and is similar to Segment 5.

Segment 11. This is a very busy segment. It consists of a populated area along a two-way freeway system.

The intensity and step threshold settings for the two experiments we performed are presented in Table 5. The 350 frames processed by the Autoscreener/FLIR for each experiment came from the same eleven imagery segments but they were not necessarily the same frames.

TABLE 5. THRESHOLD SETTINGS

Imagery Segment	Run #1			Run #2		
	Intensity Threshold			Intensity Threshold		
	Hot	Cold	Step	Hot	Cold	Step
1	4.4	4.4	0.65	4.4	3.6	0.55
2	4.4	4.4	0.65	4.4	3.6	0.55
3	4.4	4.4	1.10	4.4	3.6	0.55
4	4.4	4.4	1.10	4.4	3.6	1.00
5	3.3	3.3	0.30	3.3	3.6	0.18
6	3.3	3.3	0.30	3.3	3.6	0.18
7	3.3	3.3	0.30	3.3	3.6	0.18
8	3.3	3.3	0.30	3.3	3.6	0.18
9	3.3	3.3	0.30	3.3	3.6	0.18
10	3.3	3.3	0.30	3.3	3.6	0.18
11	3.3	3.3	0.30	3.3	3.6	0.18

The performance of the Autoscreener/FLIR system was evaluated by recording the processed imagery frames with symbols on Visicorder paper and then comparing the results with the video imagery. Table 6 summarizes the scoring per sector. If one or more man-made objects were in a sector, this represents one MMOs sector. If a sector contained one or more MMOs and they were not detected (no symbol was displayed), this represents

TABLE 6. SCORING RESULTS WITH HIGH THRESHOLD SETTINGS

Run #1					
Image Segment	Frames Processed	Sectors with MMOs	Detected Sectors with MMOs	Missed Sectors with MMOs	Sectors with False Alarm
1	23	23	19	4	1
2	34	34	30	4	7
3	21	7	7	0	2
4	19	19	16	3	17
5	24	44	29	15	4
6	42	214	174	40	23
7	42	89	76	13	13
8	21	95	87	8	8
9	36	19	5	14	8
10	67	136	114	22	24
11	25	232	214	18	28
Total	354	912	771	141	135

TABLE 6. SCORING RESULTS WITH HIGH THRESHOLD SETTINGS

Run #2					
Image Segment	Frames Processed	Sectors with MMOs	Detected Sectors with MMOs	Missed Sectors with MMOs	Sectors with False Alarm
1	18	18	18	0	0
2	23	23	23	0	15
3	33	9	9	0	9
4	16	16	16	0	11
5	27	51	47	4	2
6	42	227	215	12	28
7	42	97	91	6	17
8	13	64	59	5	3
9	35	21	21	0	54
10	81	176	166	10	47
11	17	171	161	10	26
Total	347	873	826	47	212

a missed MMOs sector. On the other hand if a sector contained no MMOs and a symbol was displayed, this was considered as a sector with a false alarm. The image segments, the number of frames processed and scored, the number of sectors with MMOs, the number of detected sectors with MMOs, the number of missed sectors with MMOs and the number of sectors with false alarm are presented in Table 6 for run #1 and run #2.

The video imagery frames processed by the Autoscreener/FLIR system with the target symbols were recorded on a Visicorder which was used with the video imagery (ground truth) to extract the information of Table 6 about the detected, missed and false alarm sectors. The work is tedious and time-consuming which is made more difficult by the limited dynamic range of the Visicorder. Subsequent studies should use a video disc for storing the processed video imagery frames. At the same time all the video imagery as well as the symbols generated by the Autoscreener/FLIR system were recorded on 1/2 inch video tape recorder for subsequent viewing. In spite of the limitations of having to record a second dubbing of a video imagery without a time base corrector (TBC), the results are surprisingly good.

The probability of MMO detection P_D is the ratio of the number of detected sectors with MMOs to the total number of sectors with MMOs. The probability of miss is $P_M = 1 - P_D$. The probability of false alarm P_{FA} is the ratio of the number of sectors without MMOs but detected to have MMOs to the total number of sectors without MMOs. The results for the two runs are presented in Table 7. Run 1 represents the case where the thresholds, especially of the step, are high which results in a relatively low probability of detection (high probability of miss) but low probability of false alarm.

TABLE 7. PROBABILITY OF DETECTION AND FALSE ALARM

	Run 1	Run 2
P_D	84.50%	94.60%
P_{FA}	2.80%	4.50%
False alarm rate per frame	0.38	0.61
No. of frames per false alarm	2.60	1.60

In Run #2 the thresholds were lowered which resulted in an increase in the probability of detection with corresponding increase in the probability of false alarm and decrease in the probability of miss. However, the ΔP_D is greater than ΔP_{FA} and this is the desired outcome.

The false alarm rate gives the number of false alarms per processed frame and is given in Table 7. In Run #1 we have one false alarm per 2.6 frames while in Run #2 we have a rate of one false alarm per 1.6 frames.

The above two points are plotted in Figure 22 where the results of the Autoscreener with the IR scanner sensor are presented. The results of the IR scanner are, as expected, better for two reasons. First, the IR scanner data are much better (high signal-to-noise ratio and higher resolution) than the FLIR data, and second, the constant thresholds do not affect the

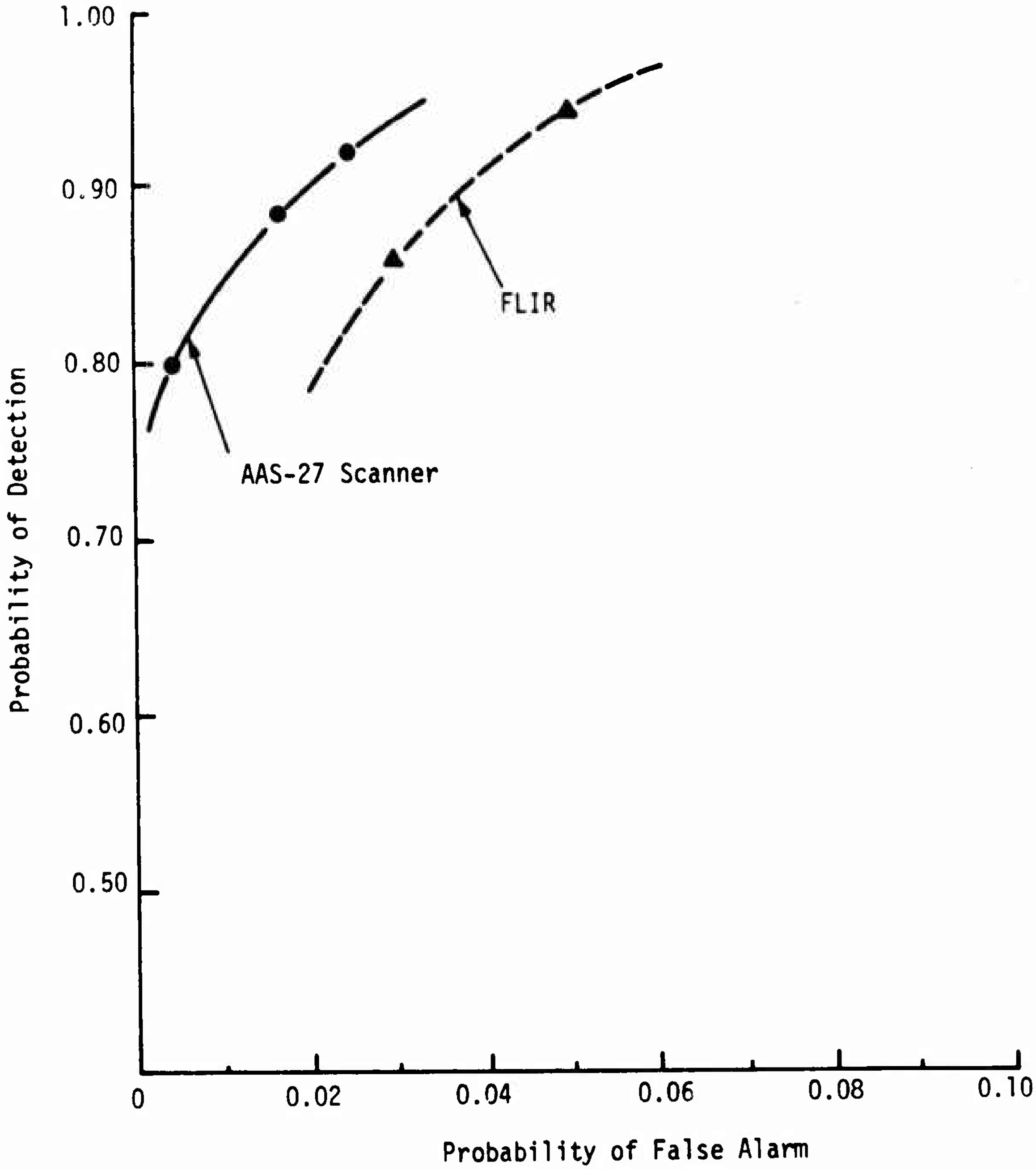

Figure 22. Autoscreener Performance: Sector Basis

results of the Autoscreener with the IR scanner but affect the FLIR data dramatically. In the latter case if the thresholds are set low so that the system will detect objects at the maximum possible distance, the false alarm rate will be great as the FLIR sensor closes in on the target. Similarly, if the threshold settings are optimum for close ranges, many targets will not be detected at large ranges. Consequently, the probability of false alarm will be low; however, the probability of miss will be high. The incorporation of an AGC circuit and an automatic (or adaptive) threshold with the Autoscreener will optimize its operation.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

In this section, a brief summary of the contents of this report is presented, followed by the conclusions we reached at the completion of this program, and finally our recommendations are presented.

SUMMARY

In Section 1, the Autoscreener story is presented, the objectives and results of this program are stated.

In Section 2, the remaining sections are summarized.

In Section 3, the Autoscreener/FLIR system description, its operating instructions and its theory of operation are presented.

In Section 4, the hardware and software modifications of the original Autoscreener, to make it compatible with the TV-compatible FLIR system, are described.

In Section 5, the performance evaluation of the Autoscreener/FLIR system and the results of 95 percent probability of MMO detection and 5 percent false alarm probability are discussed.

Finally, in Section 6 a brief summary of this report, our conclusions and recommendations are presented.

CONCLUSIONS

At the completion of this program, Honeywell is able to make the following conclusions:

1. We have established the feasibility in detecting man-made objects and cueing the FLIR operator with the Autoscreener. We achieved 95 percent probability of MMO's detection with less than 5 percent probability of false alarm. This was achieved with FLIR imagery nowhere near the quality of the AAS-27 imagery.

2. The scan converter is an interim, very cost-effective and fast approach in assessing the feasibility of the Autoscreener/FLIR system in detecting MMOs and cueing the FLIR operator. The scan converter has limited dynamic range, non-uniform response throughout the electrostatic tube and is another source of noise.

3. The FLIR imagery, because of its aspect angle dependence, is not as well behaved as the AAS-27 imagery. The intensity increases from the top of each frame to its bottom and varies inversely proportionally to the range squared from the sensor to the object. Thus, the absence of a AGC circuit and automatic threshold has a detrimental effect on the results. If the Autoscreener thresholds are optimized for large ranges, the Autoscreener detects small MMOs (6 x 6 pels), but as we close in range, the false alarm rate increases. On the other hand if the Autoscreener thresholds are optimized for close range, legitimate objects at large ranges are missed.

4. The seven feature histograms indicate that we may have correlated features. The best set of features may be a combination of existing features based on shape and new features based on texture.

5. The Autoscreener/FLIR system with the scan converter processes one FLIR frame per second (or one frame per 30 TV-compatible frames). The recorded symbol on the output display and Visicorder indicates the proper location of each sector containing MMOs, but on the monitor (input display) where every frame of the TV-compatible FLIR is displayed, it appears that there are missed MMOs and false alarms. This arises because the displayed symbol corresponds to an imagery frame two seconds earlier than the present frame. With a faster processor this can certainly be corrected.

RECOMMENDATIONS

We have proved the feasibility of detecting man-made objects in DLIR or FLIR imagery. This is very encouraging for the development of an automated Autoscreener. With this in mind the following recommendations are made:

1. The Autoscreener/FLIR system with an autothreshold will take care of the aspect angle and range dependence of the FLIR intensity and will automate the operation of the system.

2. Now that the feasibility of detection of MMOs is proved, we must turn our attention to the detection and recognition of tactical targets. We must study the optimum selection of geometric and texture features and train and test the Autoscreener classifier

with data from different environments and time of day. Its performance should be evaluated on a wide data base.

3. The first generation Autoscreener is a reality. Now is the time to consider the second generation Autoscreener. This should include an in-depth study to define the requirements of a cueing device for the appropriate mission scenarios. We must study in greater detail the speed of operation (eliminate the scan converter), the processing algorithms, the features for tactical target detection and recognition, the hardware implementation for a small, lightweight and fast Autoscreener. Finally, the Autoscreener application for ground base and airborne systems should be investigated and tested.

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